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SOME OBSERVATIONS ON THE SUBJECT OF THE IMPROVEMENT OF SEVERAL OF THE RIVERS OF THE ATLANTIC COAST.

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WITH DISCUSSION.

It has been suggested that a short article, descriptive in a condensed way of the treatment of several of the tidal rivers of the Atlantic coast, with some comments thereon, may be interesting as a basis for discussion by the Society. What follows is the outcome of that suggestion.

It is proper to observe in the outset that brevity requires the avoidance of much detail. Should a discussion ensue, what it may lead to remains to be seen. The writer also wishes it to be understood that while the statements of this article are based upon his own experience, he desires to abstain from the didactic or dogmatic style, which is nowhere more unbecoming than in writing about the manipulation of the great forces developed by water moving in the channels of rivers, where

so many of the elements to be taken into account are constantly changing, and so much is uncertain because undiscoverable even after long study and observation. One ounce of experience is worth tons of mere theory.

The art of river engineering is much like that of the physician. There are great principles to be followed by the practitioner in each of these professions, but their application must be varied to suit the physical constitutions of the patients, and all these differ from others at the same time, and from themselves at different times. Underneath all the knowledge that study and experience can give must be a large stratum of hard common sense, or the result will be failure. The wise man is he who learns from his failures as well as from his successes. The physician has the advantage of the engineer that many of his failures are hid from mortal sight, whereas rivers badly treated not only live on but are sure to give full exhibition of the mistakes practiced upon them. Nature will avenge herself.

Improvement of the approach to the Harbor of Baltimore.

This improvement is partly in the Patapsco River below Baltimore, and partly in Chesapeake Bay, below the nominal mouth of the river. The Patapsco, below Baltimore, though called a river is rather an arm of Chesapeake Bay (see Plate XXXIV*). Above Hawkins' Point there has been always a greater depth than below. In early days the main obstruction to navigation was the great shoal extending southeastwardly below Hawkins' Point to the Seven-Foot Knoll. Through this shoal there was originally a meandering channel with a depth of about 18 feet at mean low water with an average rise of tide of 18 inches. Eastward of the Seven-Foot Knoll the channel had a somewhat greater depth, as shown on the map herewith, on which its original direction towards Swan Point and thence southward to the deep water of the bay is still given.

The first proposition to give a channel of a greater than the natural depth appeared about thirty-five years ago, and came from the late Colonel (then Captain) Henry Brewerton, of the United States Corps of Engineers. The plan was to give a straight channel along the line of the existing Brewerton Channel, with a depth of 22 feet at mean low water, and a width of 150 feet; which was to be excavated by dredging wherever necessary in the original line towards Swan Point. There

*It will be observed that the illustrative maps have been made as small as possible to avoid expense and to conform to the size of the volumes issued by the Society. Those who wish to see a map showing the relations of the Patapsco to its surroundings are advised to refer to some large atlas or specially to the printed map of the Coast Survey, No. 384, corrected to 1887.—W. P. C.

were few dredges in the United States in those days. After advertising for proposals for two or three years, no contractor could be induced to undertake the work at a reasonable price. Four dredges of the Osgood pattern were thereupon built by the United States, with dumping scows and an attendant tug-boat.

The work went on slowly, but as rapidly as the meagre and intermittent appropriations of Congress allowed, until brought to an abrupt termination by the war of 1861–65. With the revival after the war came a change of plan. The commercial interests of Baltimore demanded a greater depth of channel, which was increased to 24 feet at mean low water, with a width of 300 feet. With these changes came also another, viz., of location of the portion of the channel eastward of Seven Foot Knoll.

It had been observed that it was difficult if not impossible, except by constant dredging, to keep the channel east of Seven Foot Knoll deeper than nature made it. The cause of the filling was obvious—the sweep of the currents directly across it, both on the flood and the ebb of the tide, to say nothing of the fluvial matter brought down from the Susquehanna in freshets.

A careful study of the situation by the engineer then in charge called attention to two important conditions: The first was, that, considering as two great forces the two great masses of water meeting near the line from North Point to Bodkin Point, their resultant might be expected to be in direction nearer that of the greater, and in plan near the western rather than the eastern shore. With this idea in mind, study of existing maps indicated that, in an area not very distant from the western shore of the bay below Seven Foot Knoll and parallel to it, there was much deep water, with free passage through it, interrupted by lumps marked "hard." An examination of these lumps showed their hardness to be due very much to layers of oyster beds, living and dead, but with deep water quite near them.

It seemed reasonable to conclude that nature had been doing her best to make a deep channel in this natural position, and that, if these hard masses were removed, good results would follow. And so they did, the dredge being the agent. The change of plan was approved in Washington. Liberal appropriations were made by Congress, which, in order to expedite the work, were supplemented by the City of Baltimore under the wise lead of Mr. John W. Garrett and other public-spirited citizens. The channel was completed in 1874, the depth being 24 feet at mean low water, and the width 300 feet. To give this depth to the City of Baltimore, some dredging was also necessary above Hawkins' Point. The effect of the improvement in increasing the commerce of Baltimore was very marked, as also in changing the character of the vessels carrying it, as it permitted for the first time the use of the larger steamships suited to trans-oceanic navigation.

Another improvement in the channel was suggested: the excavation of what is now called the Cut-off, which is in the line of an old swash-channel. This was also a natural channel, but much of the material through which it ran was too hard to be removed by the water alone.

It had been observed that the lower portion of the shortened Brewerton Channel, that is, the part between the tangent to the western shore above North Point and the intersection of the Brewerton and Craighill Channels, was more liable to deterioration than the portion westward of that tangent, and it was thereupon determined to adopt as the main channel the line of the Cut-off, and abandon the portion of the Brewerton Channel below the upper end of the Cut-off. This idea has been carried out in connection with a still farther enlargement of the dimensions of the channel demanded by commerce. The plan now in process of execution is to provide a depth of 27 feet at mean low water, w th a width of 600 feet. The depth of 27 feet is already secured to Baltimore. A width of 400 feet with that depth exists throughout the Craighill division up to the Cut-off and through the Cut-off. Above the Cut-off to Baltimore the width is but 300 feet.

The advantages to Baltimore from the improved channel are obvious. Formerly, large ships could only come to the city or leave it with partial cargoes. Lighterage was done in the bay, some 20 miles below. This branch of business has disappeared altogether. When the Great Eastern came up Chesapeake Bay she was obliged to remain as far down as the vicinity of Annapolis. Now she could readily come to Baltimore.

The small vertical range of the tide, averaging 18 inches, has made it necessary to dig deep to obtain a sufficient depth for navigation at all stages of the tide. But this small vertical movement is an advantage in one sense, as, because of it and of the broad expanse of water in which the artificial channel is made, the velocity of the currents is less and the consequent amount and movement of matter in suspension is small. These circumstances favor the permanence of this channel, a thing to be rarely expected of a dredged channel, unless regulating works be added.

The idea of such training walls in this harbor has been considered, but their presence would be strenuously opposed by the great number of navigators in smaller vessels, especially sailing craft and light draught steamers, which need not go in the deep channel and have occasion to be outside of it. The constant use of the deep channel by the large screw steamships of oceanic lines helps greatly to keep the channel clear, and while it may be necessary to occasionally redredge it in one or two small spots, the annual repair of this kind is small, and less than the interest on the first cost of long training walls which would also need occasional repairs.

It has been objected that the dredges are much in the way while at work. This is true, but the objection lessens in force as the width of

the channel increases and approaches its limit. On the other hand the dredges are entirely out of the way when not at work, whereas training walls in this locality would be a constant obstruction and danger to navigation, and serve as places of lodgment for the ice which sometimes though rarely fills the harbor.

Of late years the dredging has been done entirely by contract. The old, original dredges were long ago sold. They needed much and expensive repairing to keep them up to their full capacity for work, which was small, not exceeding 400 to 600 cubic yards of material a day. They were, moreover, a constant subject of worry and contention for the engineers who wished to have the crews of the best material without regard to their politics. The politicians took a different view and sometimes carried their point against the engineer. The large dredges of the present day can do five times as much work in good weather, and can work in much weather which would oblige the old style dredges to go to a harbor for safety. The price of the dredging has been also very greatly reduced, viz., to about one-third of what it formerly was.

The disposition of the dredged material is a matter of great moment, especially when the quantity runs up into the millions of cubic yards. The important point is to put it where it will do no harm in the future. If it can, moreover, be put where it will actually do good, there is a great gain. The general rule adopted here has been to prescribe that material taken from the channel may be dumped in the bay, but not nearer the dredged channel than a mile east of the Craighill division and a mile south of the Brewerton division. By this disposition of the material and its spread over a large area, no obstruction to navigation is caused and there is small probability of any portion of the deposited matter working back into the channel or becoming otherwise hurtful. Moreover, from the space this mass occupies an equal volume of water is kept out and is thus compelled to take its place in the excavated channel.

In excavation no effort has been made to give with the dredge any specified slopes to the sides of the dredged channel. To require anything of that kind would cause contractors to raise their prices, even if the whole work were contracted for at once. In this case, where the work goes on by successive additions to the width from year to year, under the present system (or rather want of system) of intermittent and insufficient appropriations, the best way has been in any one season to make the sides of the excavation practically vertical. As the side slope slips in, the dredge keeps the bottom clear until the natural slope in the water is gradually taken. If a particular slope were assumed in the beginning and required of the contractor, natural causes would be almost sure to change it and redredging be required if the prescribed slope were too great; or, if the prescribed slope were less than the natural, in order to insure stability, more material would be generally taken out than necessary, and at a greater cost than by the method pursued.

It will be noted that the channel is in straight lines. The consequence is greater ease of navigation. The channel here is well marked by range lights. The navigator coming up the bay soon finds the range of the Craighill division. He follows it in a line very nearly north and south until he is on the range of the Cut-off, along which he continues in another straight line until he is on the range of the Brewerton division, and he is thus brought within sight of the city and near well-known land-marks.

Objection has been made that some dredging will be needed occasionally to keep this channel in good condition. The length is about eighteen miles. The annual cost of dredging will not exceed from $30 000 to $50 000. This does not seem a large sum when the advantages of the improvement are taken into account and consideration is given to the need of keeping in repair all artificial highways, such as railroads, canals, common roads, streets, etc. The main need for annual repairs at this time is caused by the narrowness of the channel. When a great steamer shears a little and strikes a glancing blow against one of the banks of this canal dug in the bottom of the river and without revetment, her sharp prow, like a plow, makes a huge furrow and throws a large mass of mud into the water way.

It may not be uninteresting to note that about three-quarters of a century ago Admiral Cockburn found an obstruction to the navigation of his fleet towards Baltimore at an insignificant little place called Fort McHenry. We do not propose to allow any hostile admiral ever again to get so near to Baltimore. The outer line of defense is now that of North Point to Bodkin Point, where earthen batteries will be located, with a turret or two on an artificial island at "Seven-Foot Knoll," which can be readily made from the material to be still taken from the channel. The inner line will be that of which Fort Carroll is the center.

Before leaving the Patapsco it occurs to me to mention and call attention to one other spot about midway between Forts Carroll and McHenry where our glorious air, "The Star Spangled Banner" of Frank Key was born. Long may that banner wave, not only on the Patapsco, but over this whole broad land,

"The land of the free and the home of the brave."

James River, Virginia.

The portion of this river which has been the subject of improvement is that below the City of Richmond, the head of tide-water and of navigation. The improvement was regularly undertaken by the United States in 1870. A small sum had been previously expended, but with little advantage. In addition to the appropriations from the general treasury the City of Richmond has contributed her money liberally towards the expense of this work, in which she is vitally interested.

When the improvement was begun by the United States, navigation was much hindered by sunken vessels, the remains of military bridges, and other obstructions put in the river during the late war to prevent the national fleets from approaching too close to Richmond. There were also natural obstacles. Rockett's Reef, at the border of the city (Plate XXXV), and Richmond Bar, a short distance below, had each only 7 feet of water at mean low tide. From Warwick Bar (where the depth was 13 feet) to Richmond the channel was crooked and obstructed by dangerous rocks and ledges. The Dutch Gap cut-off, which now saves 5½ miles of difficult navigation, was not then open (Plate XXXV).*

The original project was to secure a depth of 18 feet at full tide, corresponding to 14.5 at low tide, with a channel width of 180 feet from Harrison's Bar to Richmond Docks, 37½ miles above, the excavation in rock to be 18½ feet at full tide. This project was well advanced when Congress, in 1884, ordered that subsequent operations should be directed to the attainment of a depth of 22 feet at mean low tide from Richmond to the sea (Plate XXXVI). This extended project is an expensive one, as it requires the removal of a large quantity of rock. In carrying it out, the width proposed for the channel is 400 feet from the sea to City Point, where the James receives the waters of the Appomattox; 300 feet from City Point to Drewry's Bluff,† which is about 7 miles below the city, and 200 feet thence to Richmond. The change from the former to the latter project was a great one and rendered useless much of the work already done. Very little money has thus far been available for the new scheme.

The methods employed for improving the river have been dredging, rock excavation, and the contraction and regulation of the water-way by training walls and wing dams. The rule has been to use the small and inconstant supply of funds in attacking always the shoalest places, with a view of obtaining the greatest benefit to commerce in the shortest time.

The present condition of the river may be known from the fact that vessels drawing over 16 feet can now be loaded to that depth at the city and go out. (Plate XXXVII.) The United States ship Galena is expected up soon and will not on this occasion stop at Drewry's Bluff.

As is usually the case, the main trouble has been with the straight and wide reaches of the river, and at points where there is a cross-over of the channel from one side to the other, due to change of curvature of the river or to some local cause. By far the most expensive part of the improvement has been and will be, the few miles from Richmond

* See also Coast Survey Chart 402, showing the Appomattox and the James Rivers above City Point.

† The line A B on Plate XXXV, is the same as the line A B on Plate XXXVIII. If one line were placed over the other, the two plates would show the relative directions of the James and Appomattox Rivers.

to Drewry's Bluff. This is to be attributed to a great extent to the physical characteristics of that portion of the river, and chiefly to the necessity of removing a great quantity of rock.

The rock in this river is granitic, partly in beds and ledges, and partly in detached boulders. There is much of it which has never been compacted or has become disintegrated, and is so soft as to be readily removed by a strong dredge. Before the war the City of Richmond had done some dredging of sand and mud from the worst shoals and had taken out some loose rock. The dredged material was not disposed of to the best advantage, being often dumped where much of it came back into the channel again.

The first operation undertaken by the General Government was that most needed—the removal of the artificial obstructions. This was quite a tedious though a comparatively simple job. The worst place was at Drewry's Bluff, where the natural channel had been completely closed by sunken vessels. A narrow channel was formed in an unnatural position close to the left bank. This arrangement brought vessels better under fire from the powerful batteries on the bluffs of the right bank. The remains of a number of steamers (some iron-clad) and sailing vessels, as well as cribs filled with stones, were removed at Drewry's Bluff by the aid of the diver, explosives, dredging and hoisting apparatus. Vessels and the remains of military bridges on piles and cribs were taken out at other points.

At the same time the opening of the Dutch Gap cut-off was systematically begun. It had been attempted during the war under the direction of General Butler, but the work was too much hindered by hostile guns at that time.

By making this Cut-off, the improvement of Trent's Reach, one of the worst places in the river, became unnecessary, and a distance of 5½ miles was saved to every navigator.

The next steps in the improvement were the beginning of the construction of a system of training walls and wing dams to give an increased depth of water in a narrower and regulated channel, with the use of the dredge to remove the worst parts of the worst shoals, in order to give immediate relief to navigation, which could not wait for the slower operation of regulating works. This great use of the dredge gives certainly quick results, but it is an expensive method of procedure, as a freshet of a few days' length has often obliterated the work of months of one or more dredges. But the people will have it so.

Whenever any part of the meagre appropriations could be spared for the construction of regulating works, some progress was made with them. Besides this function, these works gave places behind which the dredged material could be deposited, a matter of very great importance. It has saved very much expense when such material could be disposed of by being carried by water from the dredges, and dumped immediately

from the scows behind the training walls and spurs. When it becomes necessary to remove it to the banks of the river and rehandle it, the expense is much increased.

The adoption of a system of regulating works requires the engineer to decide at any particular locality, whether to rely on longitudinal training walls or wing dams, or a combination of both. In some respects, the longitudinal training walls would be preferable, if it could be always known with certainty where to put them, and have the best results for the money spent. In most cases it is impossible to decide this point with absolute precision. Even at the mouth of the Mississippi River, when the problem was in the hands of so able a man as Mr. Eads, he found it expedient to use spurs in addition to his original training walls.

It may be said of longitudinal training walls, that if they are put in deep water they become very expensive. If placed too far from the channel to be improved, their effect is insufficient. If placed too near, they are likely to be undermined.

On the James River, the arrangement of the regulating works has been arrived at in the following manner. After the surveys and maps were made and due investigation was had of the requirements of the case, the formulas told what should be the width of channel of an assumed depth and shape, which a river with the characteristics of the James would bear. Inasmuch, however, as a river is seldom the same creature for two successive days, and the variations of regimen in a year are large, there are, for these and other reasons, elements which cannot be accurately taken into account by the rigid rules of mathematics. In other words, the best hydraulic formulas give but approximate results. Woe to the man who follows them strictly!

Under these circumstances, the method of improvement must be to some extent tentative. If one bank of the river is firm and the shape of the reach favorable, spurs may be run out from the other bank, gradually, to nearly the length which would be needed to give the contraction indicated by the formulas. Observation for a year or more may show the need of lengthening all the spurs to produce the desired effect. Or, it may be found they are all too long and must be cut off. Or, it may be necessary to lengthen some and shorten some.

If the bank towards which the spurs run is liable to erosion, it must be reveted, or a training wall be built in front of it. Sometimes it may be best to run spurs from both banks simultaneously. As far as injury from undermining is concerned, the danger for spurs is less than for training walls, as only the ends of the spurs are thus exposed. When the proper length for the spurs has been determined, their ends may be connected by a longitudinal wall.

Longitudinal walls, especially if high, interfere more with the tidal reservoir, the retention of which in full is of much importance. The

spaces between the spurs are readily filled by the rising tide, and emptied on the ebb, but the swirls at the ends of spurs are often disadvantageous.

The due regulation of the height of the works is a most important matter. If too low, they control the currents too little. If too high, they obstruct them too much, especially in time of freshets or when there is danger of ice-gorges.

When a river is running one way all the time and its vertical variation is not great, the location of one spur or jetty may not be difficult. When the river is tidal and, moreover, subject to considerable freshets, the problem becomes more complicated. When more than one, a whole set, must be put in, the thing is still more difficult.

As the outer part of a spur or jetty is what mainly does the work of scour, that part should be quite or nearly normal to the thread of the current near its end. The direction of the part shoreward should be so arranged as not to check the water too much or produce scour where it would be unnecessary or hurtful. The spur should sometimes be not straight, but curved or composed of two or more straight branches.

The distance apart of spurs should depend upon the work to be done and the means of doing it. In a sluggish stream, for instance, or a sluggish part of a stream, other things being equal, the spurs of a set should probably be nearer together than in a rapid current. And in the same case more of them would be needed at the lower end of a set. The distance apart should also vary with the nature of the material to be scoured (the velocity being constant), the distance apart being lessened as the weight of the material to be scoured is greater.

The height should be regulated to make the spur do its work at the stage when work is necessary, and not be too much of an obstruction or produce too much overfall at other stages.

On the James River, as elsewhere, the question has more than once arisen as to the relative use, in time and extent, to the best advantage to the improvement of the dredge and regulating works. When public attention is sufficiently drawn to a river or harbor to cause an appropriation of money for it from the United States Treasury, quick results are demanded. The engineer is then forced to use the dredge, although he may be sure that the work in whole or in part must soon be done over again, which need not have been the case if there had been money available to construct a proper system of regulating works and the interests of navigation had permitted the delay. If he can proceed with his regulating works while the dredging is also in progress, he is a fortunate man, as he may then expect the former to hold the channel as the dredges make it.

The matter of the comparison of the costs:

First.—Of the making of a channel by dredging and its retention by the occasional use of the same means without regulating works;

Second.—Of the cost of a complete system of regulating works with the interest thereon yearly, without resort to dredging ; and

Third.—Of the combined use of the two ;—is a thing to be carefully considered in every case that arises.

It sometimes happens that owing to the rapidity of sedimentary deposition or the exposure of the locality the dredge cannot be used to make and hold the required channel. Auxiliary works are then a necessity if the channel is.

It is also rare, in considering the second alternative of dispensing with the dredge, that this is possible; because, while in dredging one may know with certainty the place where the material removed is to be deposited, there is always some uncertainty as to the effect of regulating works, and the dredge may at last be needed to attain it fully and perhaps to remove a new shoal caused by the works themselves. The case may also arise where, while regulating works will hold a channel when once made, the material is such as to require the use of the dredge to make it altogether or to hasten its completion.

He is a wise and fortunate man who knows how to use both expedients to the best advantage in aid of each other and has ample funds at his command to do what is right at the proper time, instead of being obliged to do the best he can with limited means and time at any particular stage of the improvement.

Very important lessons can be learned in this connection from the experience with the successful work of Mr. Eads at the mouth of the Mississippi River. The following statements are interesting, and come from a reliable source:

"The distance between the jetties proper is 1 000 feet. Wing dams or spurs were built in order to contract the water-way, and thereby hasten the channel deepening. The maintenance of the width of water-way between the main jetties (1 000 feet apart) was not contemplated, but they were placed that distance apart, so that by the auxiliary works they could be secured against undermining.

"From the first it was Mr. Eads' idea to close Grand Bayou ; therefore, the ultimate width of water-way through the jetties was to correspond with the average width of the pass above that bayou, which is 700 feet, in order to secure the same average depth as existed there, viz., 30 feet. Again, there were places in the channel where the material was tough clay and did not scour readily, and at such places the water-way was reduced more than at any other.

The jetties were commenced in June, 1875—the first spurs were built in June, 1876 ; and from time to time since spurs have been built. The inner jetty, on the east side, was commenced June 20th, 1882, and on the west side in February, 1886. There was no special order in which these works were built ; that is, while the inner jetty was being built on the east side, spurs were built on the west side, etc. The building of inner longitudinal works was not contemplated at the time most of the spurs were built, but later on, when it was found that considerable sand was thrown over the main jetties during storms, and worked its way into the channel, the idea of the longitudinal works (inner jetties) to prevent

this, also to prevent the escape of water at high tide, and at the same time to answer the purpose of a wing dam at every point, was adopted.

"March 24th, 1878, a section of the west jetty, 110 feet in length, commencing 430 feet from the upper end, was undermined. Piles in the row nearest the channel and at the sea end of the inner east jetty, have, from time to time disappeared, but aside from that mentioned, there has never been an undermining of an entire section. In 1876 and 1877, much dredging was done by three ordinary dipper dredges (the large dredge was not built then,) and at the same time spurs were being built. These two means were used conjointly, and places which did not readily yield to the scouring action of the current were dredged. I am of the opinion that, in time, the channel would have developed without the aid of dredging; it was only to hasten results that it was resorted to—but without the spurs, the required channel could not have been maintained even with the aid of dredging, had the water-way remained 1 000 feet in width; therefore, I consider that spurs were absolutely necessary, but dredging was not.

"As finally completed, that is, after expensive alterations had been made, the cost to Mr. Eads of the large dredge was $150 000. On a cash basis it is probable that the boat could have been duplicated for $100 000 at least.

"The boat was in commission from November 22d, 1877, to February 22d, 1883, during which time she was laid up one year on account of repairs, and because of the epidemic of 1878; therefore, she was actually in commission five years and three months, and in this time she worked three hundred days of ten hours each. About three-fifths of this time she worked in the channel between the jetties, and the rest of the time at different localities, viz., head of South Pass, above Goat Island, near Grand Bayou, and on lumps beyond the ends of the jetties.

"No dredging has been done since February 22d, 1883. At times during the past five years it has seemed probable that the services of the large dredge would be required, but that expedient has been avoided by building spurs—the prospects of her being used are no greater now. While some have often favored dredging, Mr. Eads strongly opposed it; and if, with the works as they are at present, the channel should shoal to less than the required dimensions the dredge would be used. The conditions of the channel being influenced as they are by the stage of the river, and that from year to year being a variable element, it is hard to predict what may take place from what has taken place.

"None of the spurs have ever been removed—the channel ends of some have been undermined and washed out.

"The width between the longitudinal or inner jetties is 675 feet, but at places the spurs reduce the width of water-way to 570, 590, 600 and 630 feet."

It would be interesting to consider the effects of the Dutch Gap Cut-off on the regimen of the James River. It is hoped that this and some other matters may be brought out in the discussion of this paper by two of our members who have been associated with me in dealing with this stream. The advantages of this Cut-off have led some to advocate earnestly others at Jones' Neck and Curl's Neck (Plate XXXVIII). It has also been seriously proposed to make a canal from the James, near the Dutch Gap cut-off, to the Appomattox at Port Walthall, and thus

avoid the circuitous navigation from the Dutch Gap to City Point by the present route.

While on the subject of cut-offs on the James, reference may be made to a successful improvement of the Pocomoke River, Maryland, shown on Plate XXXIX, in which a cut-off from *a* to *b* (and really to *c*) was a prominent feature, the channel having previously been by the circuitous way of *f* and *h*.

The dredge alone was used, without auxiliary works. The dredged channel has stood well. The cut-off was through a thick cypress swamp. Explosives were to some extent advantageously used on the larger stumps. My successor in charge of that improvement is making another cut-off from *d* to *g*.*

Appomattox River.

The portion of this river below Petersburg to its confluence with the James is short, being about twelve miles in length, but it has been the subject of much torment from engineers for about two-thirds of a century. This was done mainly by the expenditure of the money of the City of Petersburg. The United States engaged in the work very little until after 1870.

The map (Plate XXXVIII),† shows the condition of the river in 1855. Below the Point of Rocks nothing has ever been done, as the depth of water upon that part of the river has sufficed for the navigation. From Petersburg to Point of Rocks the river flowed through or was bordered by low, marshy ground on one side or the other. It is stated that before the war vessels drawing 9 feet could reach the wharves of the city. This was at high water, and indicated a depth of about 6½ or 7 feet at low water. During the war it was considered expedient by the Confederate authorities to close the river entirely to navigation by material obstructions. After the war the authorities of the city removed these obstructions in great measure, but the river was found to be in very bad condition, as on more than one of the shoals there was a depth of but 3 feet at low water. The navigation was down the main river to the upper end of the little gut at *a*, through which vessels passed to *b* and so out by *c* and *d*.

Besides the shoals mentioned, there were other things to be taken into account in a project of improvement. The harbor of the city was the narrow portion of the river in front of it, and this was constantly filling with sand and mud brought down from the part of the stream above Petersburg. On the eastern border of the city was a small stream

*For a description of the James and much other interesting matter see specially the annual report of Chief of Engineers, 1882, Part I, pages 860-898; and annual report for 1875, Part II, pages 74-80.

† See Coast Survey Chart 402, showing Appomattox and James Rivers together.

called Lieutenant Run, emptying into the river at right angles at *m* and bringing down in freshets a large quantity of detritus. Below its mouth the channel after crossing over followed the left bank, but in the concave, at *e*, there was some dangerous rock. The other difficulties below this point were the shoals of sand and mud.

In 1869 the engineer of the city prepared a project which contained the following features, as stated by himself:

"My plan is to straighten the river and ease the curves or bends where it can be done to advantage and with not too great an expense, and to confine it for the whole distance, from Petersburg to the Point of Rocks, by artificial banks, wherever they are needed, to one channel, expanding regularly in width from 200 to 500 feet, so as to give ample room for the freshets and flow of the tides.

"To make this plan as perfect as I conceive it could be made, I did not hesitate to abandon the present channel of the river almost entirely, for with the construction of about a mile of new channel I shall shorten the river nearly half a mile and conduct it into the old south channel, which, no doubt, was anciently the true channel of the river. In the old works it had been shut off repeatedly, but never perfectly, and when I took charge of the improvement fully half the flow of the downward water passed into it. One has only to see this beautiful body of water, with its comparative straightness, and bold southern shore, to be satisfied that with little expense it can be made the finest part of the river. The north shore or bank of this channel and everywhere else, where the bank is needed to confine the river, will be made of the material dredged from the river to obtain the necessary depth of water.

"I am satisfied from the experience of this river, and from the results shown in other rivers, that the increased impetus which this shortening and narrowing of the river and confining it to one channel must give to the freshets and tidal flow, will keep the bed of the river so scoured out that very little dredging will be required, except to strengthen the banks or make the navigation deeper."

When the United States took the work in hand in 1870, it was found that the means then used to confine the river was a high fence, made of sheeting sustained by round piling and wale pieces. About two miles of this fence had been finished. The engineer stated it had been located up to that time "wherever there is water or very low places through which the current might be diverted." In the first freshet after the building of the fence the river carried away a large part of it near $f^1 f$, as well as injuring it elsewhere. In addition, a coffer-dam had been built at much expense to make a straight channel from *g* to *h* through the rock. This coffer dam had been seriously damaged. Some dredging had also been done in the line of the channel in the Puddledock Marsh.

It had been the expectation of the engineer of the city that if the fence were built across the river at $f^1 f$, and a small cut made with the dredge through the Puddledock Marsh, the river itself would in the first freshet widen and deepen the Puddledock cut as much as was needed. This expectation was based on what had taken place on a smaller scale

at $f\,l$, where many years before "a straight cut through an island was made with shovels, the length of the cut being about ¾ of a mile, its width 10 feet at the water-line and the depth 4 feet. After this was done the channel on each side of the island was dammed up and the cut was left to the action of the river. The cut was scoured out to a navigable depth, as was stated, in about thirty days."

The river would not act in this way in the proposed Puddledock channel, but seemed to prefer the old route to the sea. The reason was probably that the island through which the cut was made in the first experiment was nothing but alluvium, whereas the soil in the Puddledock Marsh was filled with roots and stumps of cypress and other trees, and much of the material was so hard as to require subsequently a strong dredge for its removal, and explosives had to be used on some of the stumps before the dredge could start them.

The funds of the city were by this time nearly exhausted, the appropriation of the United States was small, and the pressure for immediate result was, as usual, strong. The question was what to do. The fence was abandoned, as it was too weak and not well located for its object, and the channel it was expected to provide was much larger than the river would maintain.

An examination of the history of the river showed that the "South Channel" from s, the lower end of the proposed Puddledock cut, had been quite constant and its right bank was permanent and bluff. It was decided to improve this stretch.

It was in contemplation at one time to connect this South Channel with the channel then in use by making a cut on or near the line $s^1\,s$ or ^{1} the left bank of the river above that proposed cut being also bluff and apparently permanent for some distance up-stream. As an alternative the plan of making a cut from a, past c to k, was discussed.

But as so much progress had been made on the Puddledock cut, and for other reasons, it was decided finally to open that cut with the dredge and close the river at $f^1\,f$, which was done. The idea was considered of putting into the closing work at $f^1\,f$ tide gates, automatic or otherwise, to admit the flood water by that means, and to cause the same water on the ebb to go through the Puddledock cut and the South Channel, but this was not carried out.

The advantage of making the channel take direction from g to h near the city, has been constantly recognized, but its expense, as it is in rock, has never allowed this to be done. The course of Lieutenant Run was changed so as to have it come into the river lower down and at a very acute angle. Its detritus was thus deposited in the space $g\,h$ where the straight cut was expected to be, but out of the used channel.

Some spurs on the left bank opposite the city, and frequent use of the dredge belonging to the city, are depended on to keep "the harbor" clear. Some of the rock has been taken out near e. The river below

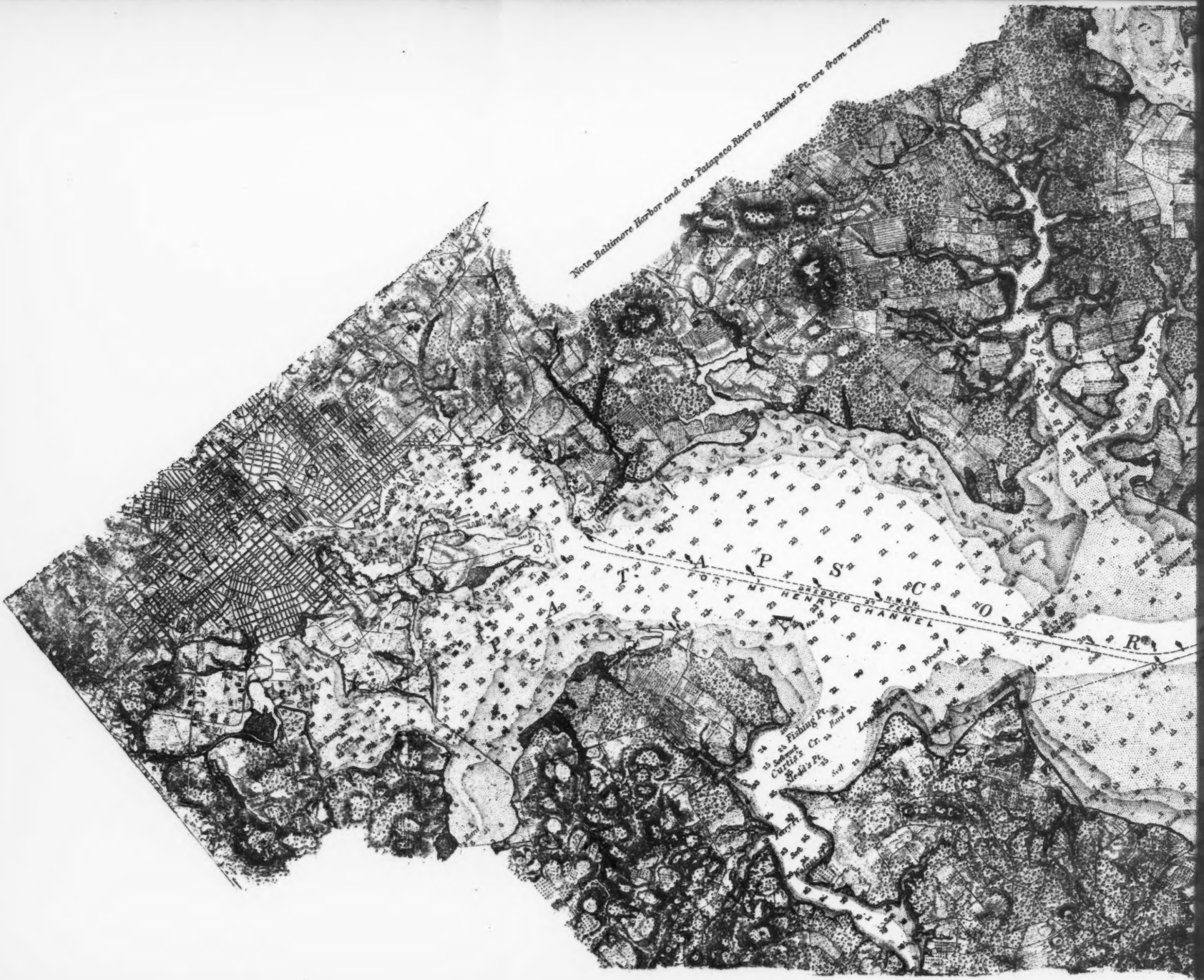
the town to the upper end of the Puddledock cut has been regulated by the training walls and wing dams to give a channel 100 feet wide and 12 feet deep at high water. Spurs have also been put on the left bank of the South Channel below the Puddledock cut to maintain the deepened dredged channel.

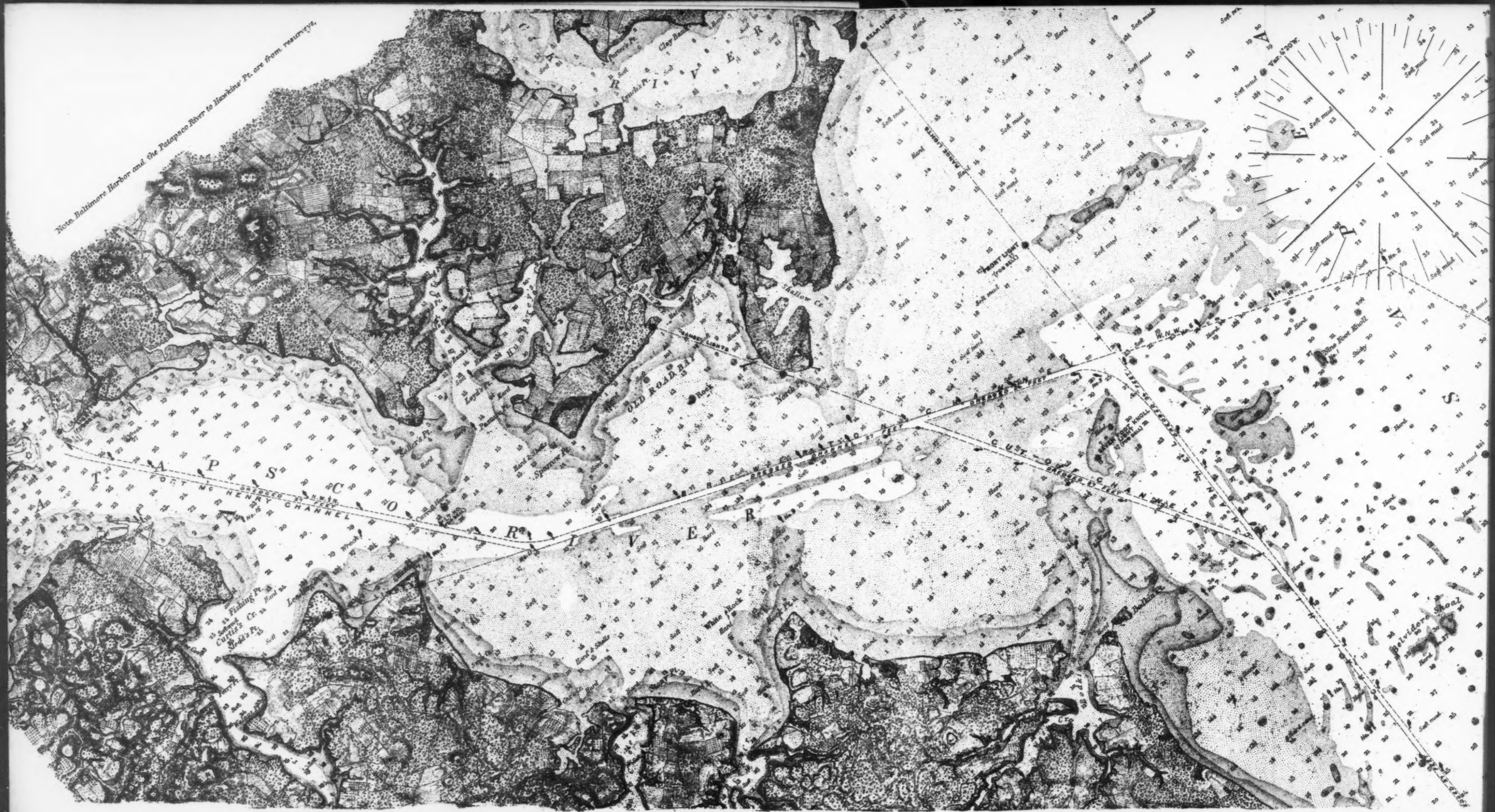
The improvement has been a successful application of the use of training walls and spurs. In the beginning, before the regulating works were put in, it was necessary to use the dredge constantly. As the regulating system progressed, the use of the dredge was continually less, until now it seldom appears upon the river. A quick freshet sometimes causes a little shoaling which the regulating works would remove in a moderate time, but the dredge is then brought into requisition to clear away the obstruction at once.

In making the cut through the Puddledock Marsh, artificial banks have been made of the dredged material. To do this, it could not, of course, be emptied in the usual way from dumping scows. A cheap and simple arrangement was used. On a small decked scow alongside an ordinary dredge a hopper was put up as high as the dipper of the dredge could lift the material. While the material was thus dropped into the hopper from the dipper of the dredge, a stream of water was at the same time pumped into it. The mixed mud, sand, gravel and water ran off together through a cheap wooden trough to form the artificial bank. This arrangement is only mentioned because it preceded, as far as the writer knows, the use in this country of the methods which have been extensively used on the Potomac Flats, at Oakland, California, and elsewhere for conveying dredged material long distances. On the Appomattox it was only necessary to have a trough some fifty feet long, which was readily carried from the side of the hopper. The same idea was also used a little later on the Wicomico River, near the town of Salisbury, Md., where the conveying trough, about 175 feet long, was supported on floats.

The artificial banks on the Appomattox and elsewhere are planted with willows, and these soon become a very dense growth, and successive crops have been extensively used for the manufacture of fascines, mattresses and hurdles which have formed parts of the regulating works.

The Appomattox is by nature a narrow stream, and the regulating works in some places make it still narrower. Some navigators find fault with the width, and it has been proposed to build a dam above Petersburg, and turn the whole river into the low grounds to the west of the present left bank, with another connection with the old river some two or three miles below. This scheme involves also the removal of all the existing works of contraction, and depends on the tidal inflow entirely for the channel below the city. It is expected in this way to be rid of deposit in "the harbor" (which would depend for its water on the tidal inflow entirely), and to have a wider channel below independent


Note. Baltimore Harbor and the Patapsco River to Hawkins' Pt. are from resurveys.
PATAPSCO
RIVER
FORT Mc HENRY CHANNEL
Fishing Pt.
Curtis's
Hedge's Pt.


Note. Baltimore Harbor and the Patapsco River to Hawkins Pt. are from resurveys.
PATAPSCO RIVER
FORT Mc HENRY CHANNEL
OLD ROAD BAY
GUT
Fishing Pt.
Curtis Cr.
Shields Pt.
Hawkins Pt.
Clay Banks Pt.
Spectacle Island
Middle Ground
Brewerton Channel
Soft mud
Hard
Rock
Lt.
Fl.
Bk.
Ch.
Pt.
Cr.

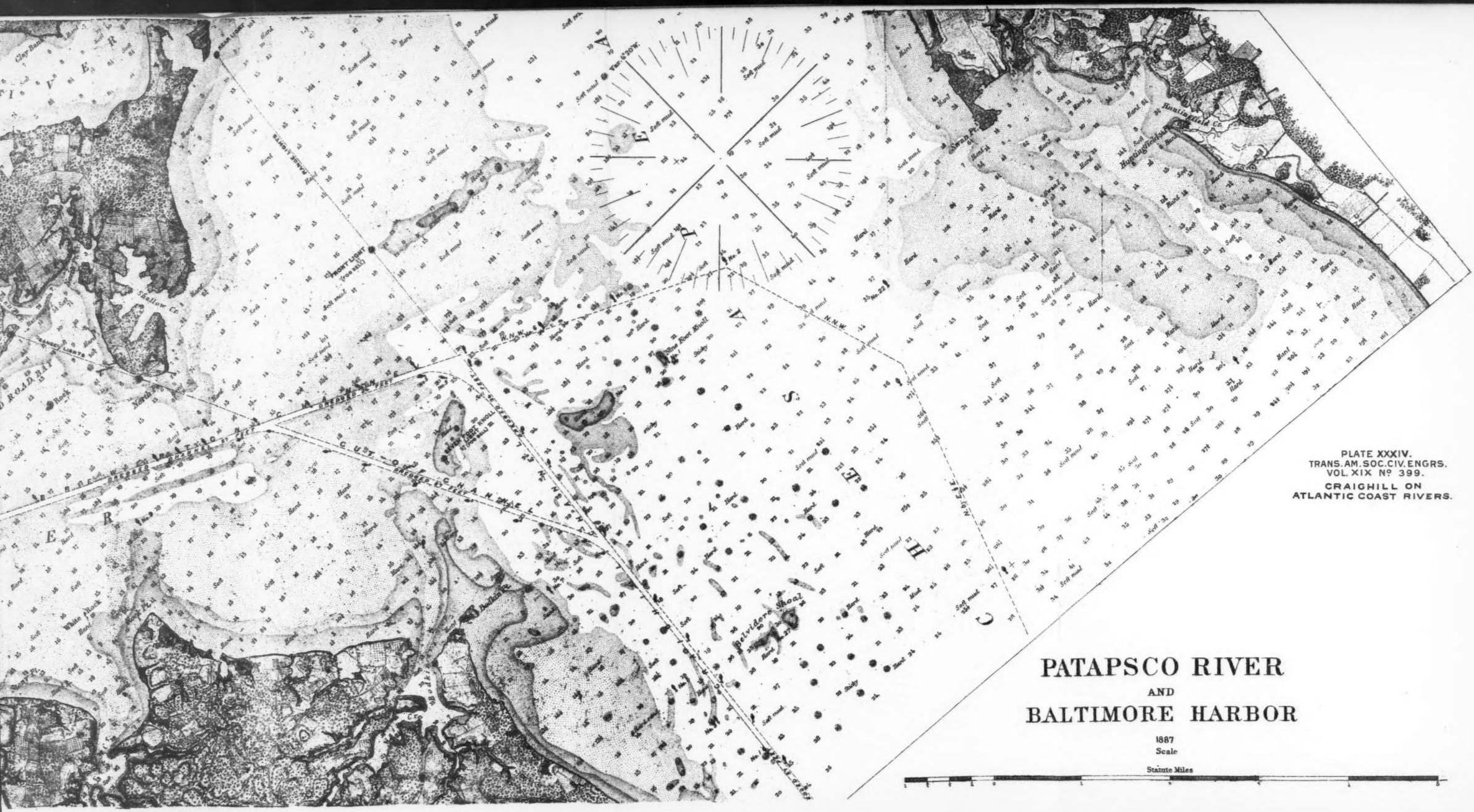


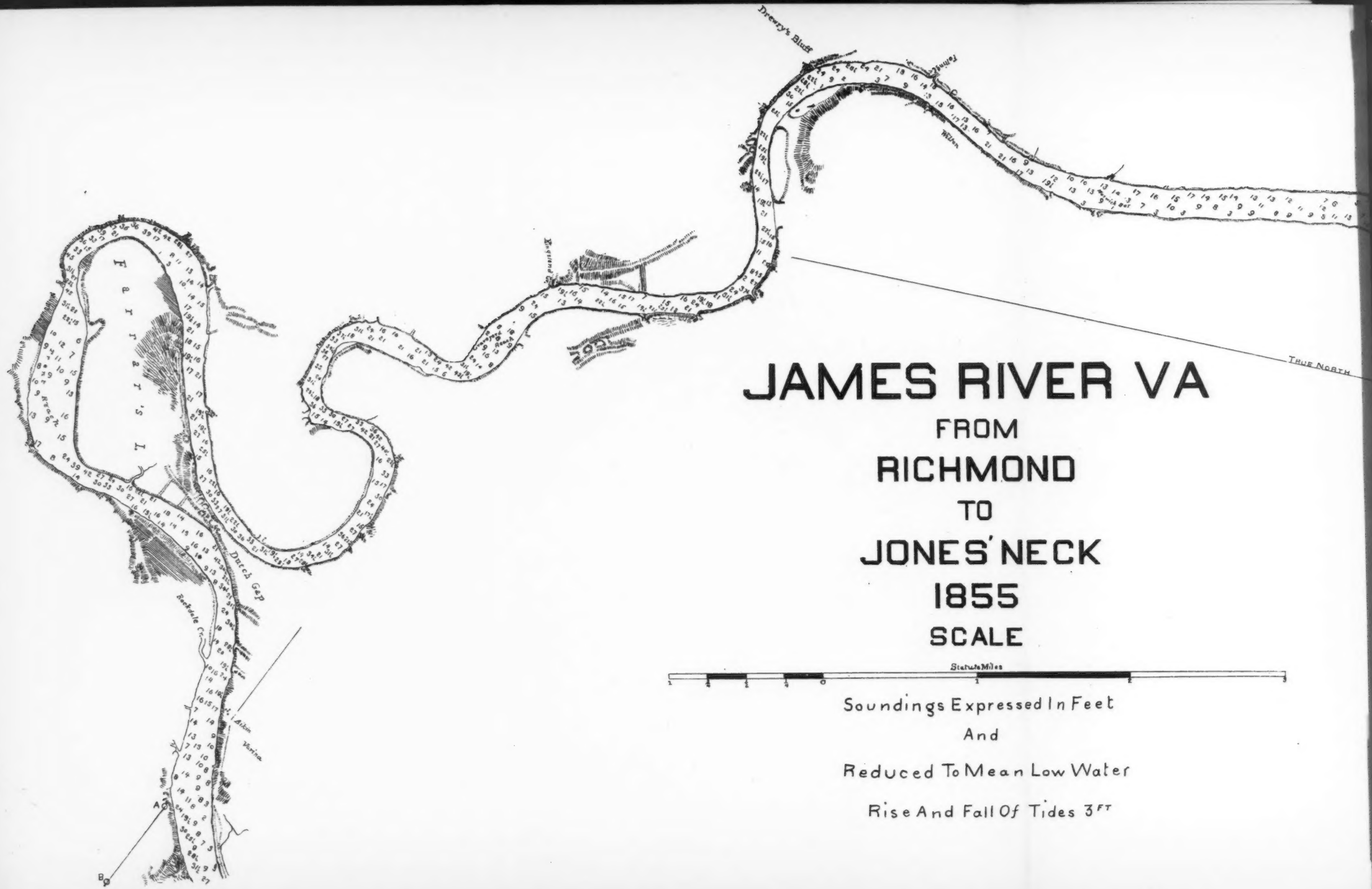
PLATE XXXIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIX Nº 399.

CRAIGHILL ON
ATLANTIC COAST RIVERS.

PATAPSCO RIVER
AND
BALTIMORE HARBOR

1887
Scale

Statute Miles



JAMES RIVER VA

FROM

RICHMOND

TO

JONES' NECK

1855

SCALE

Statute Miles

1 ½ ½ ¼ 0 1 2 3

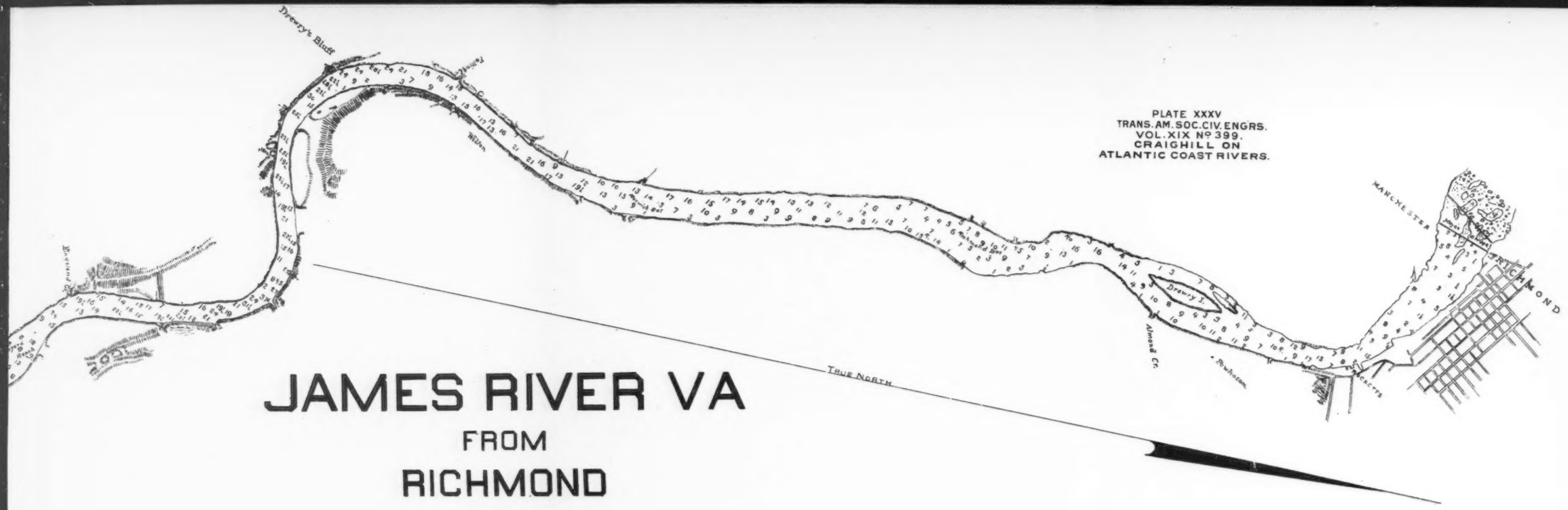
Soundings Expressed In Feet

And

Reduced To Mean Low Water

Rise And Fall Of Tides 3 FT

PLATE XXXV
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIX Nº 399.
CRAIGHILL ON
ATLANTIC COAST RIVERS.



JAMES RIVER VA

FROM

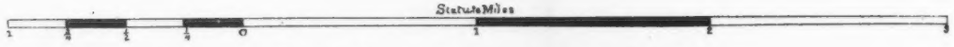
RICHMOND

TO

JONES' NECK

1855

SCALE

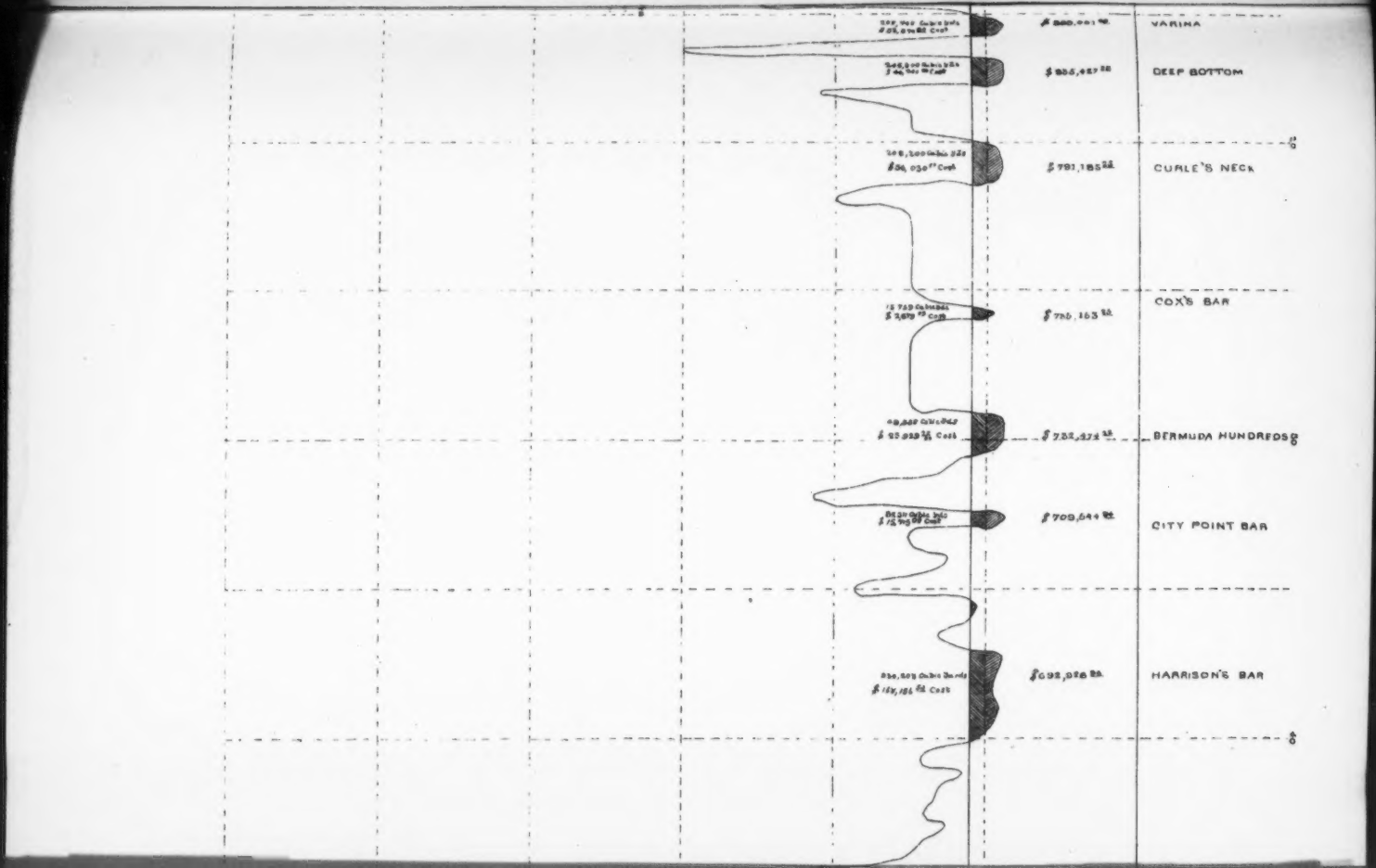


Soundings Expressed In Feet

And

Reduced To Mean Low Water

Rise And Fall Of Tides 3FT


VARINA
DEEP BOTTOM
CURLE'S NECK
COX'S BAR
BERMUDA HUNDREDS
CITY POINT BAR
HARRISON'S BAR

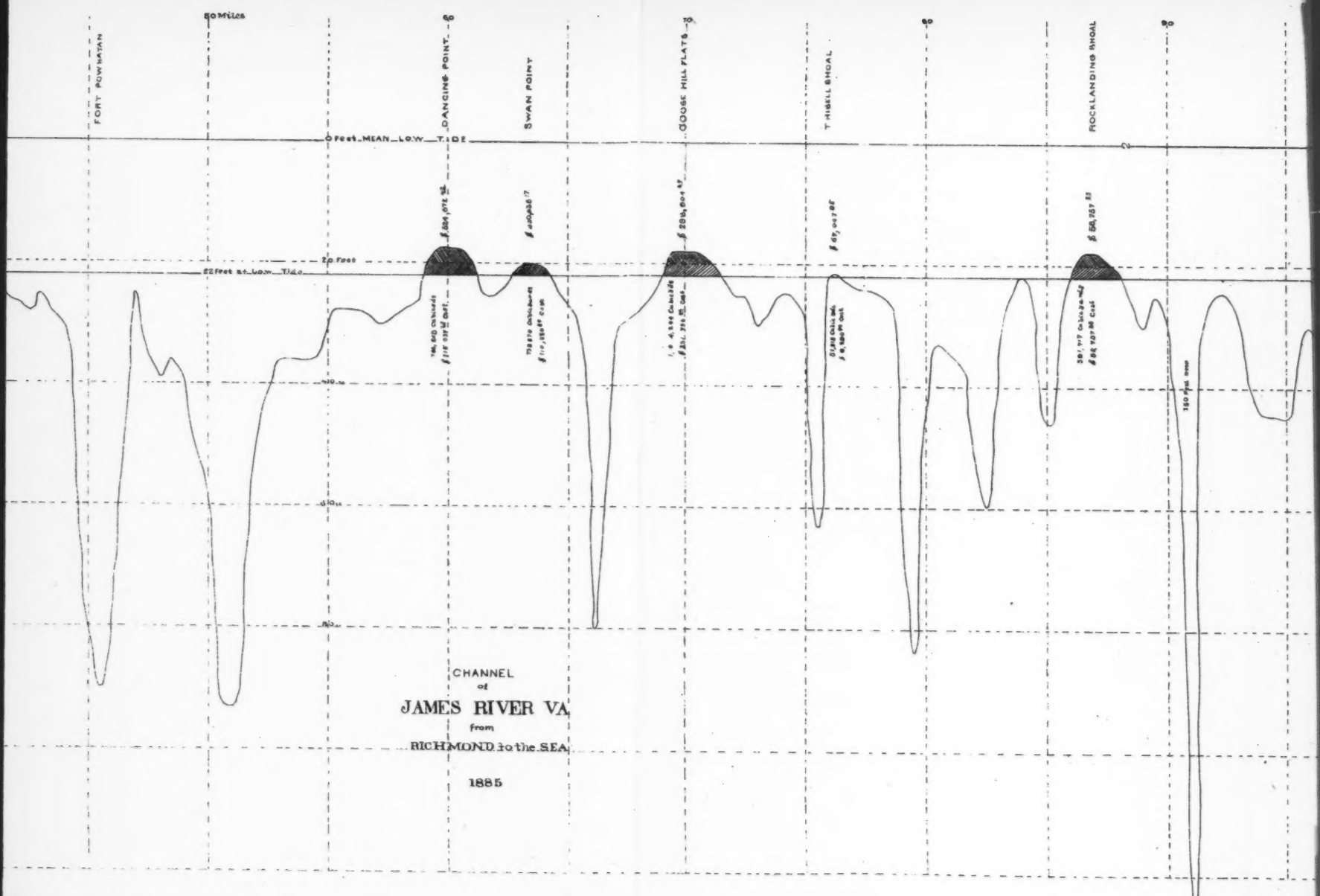
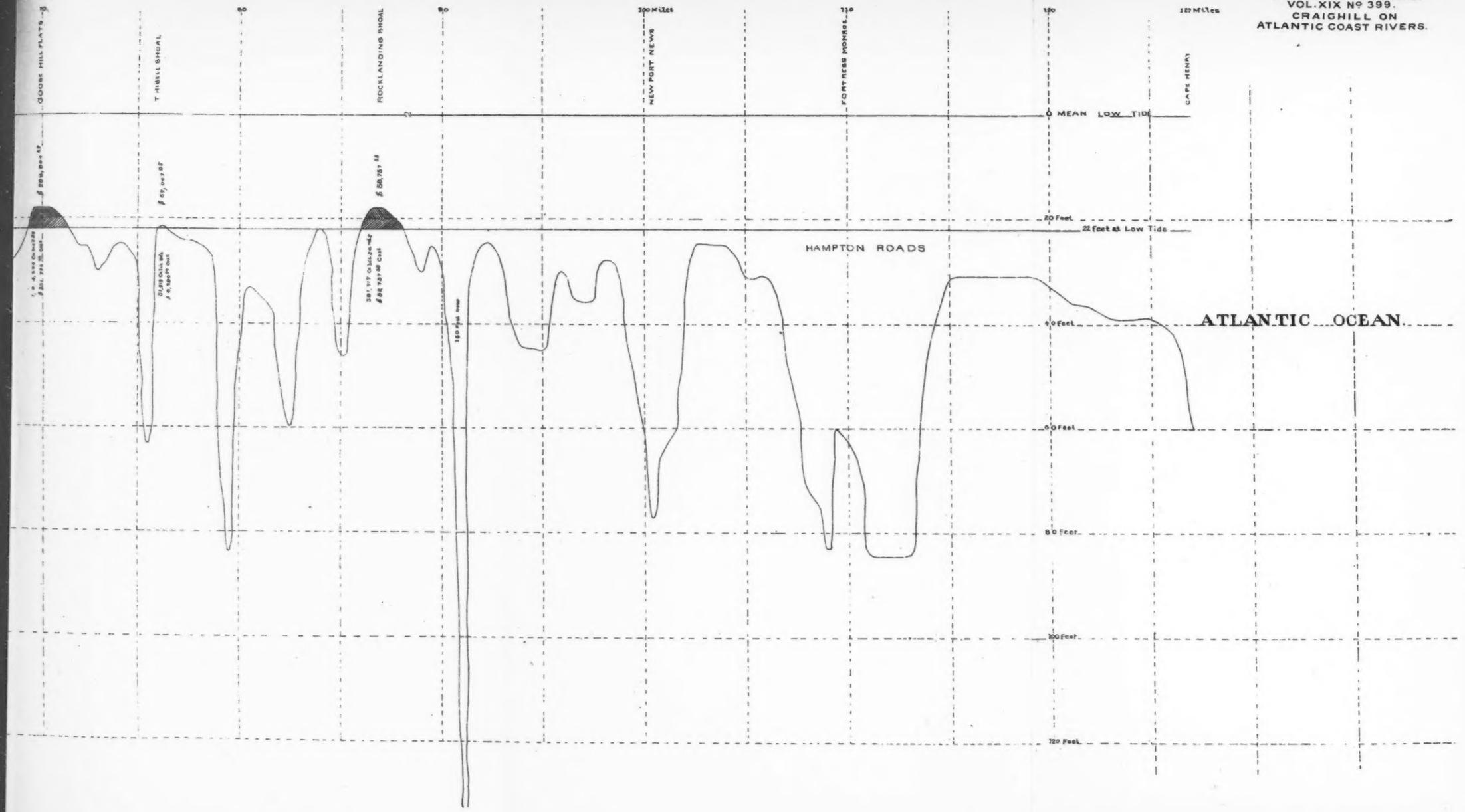
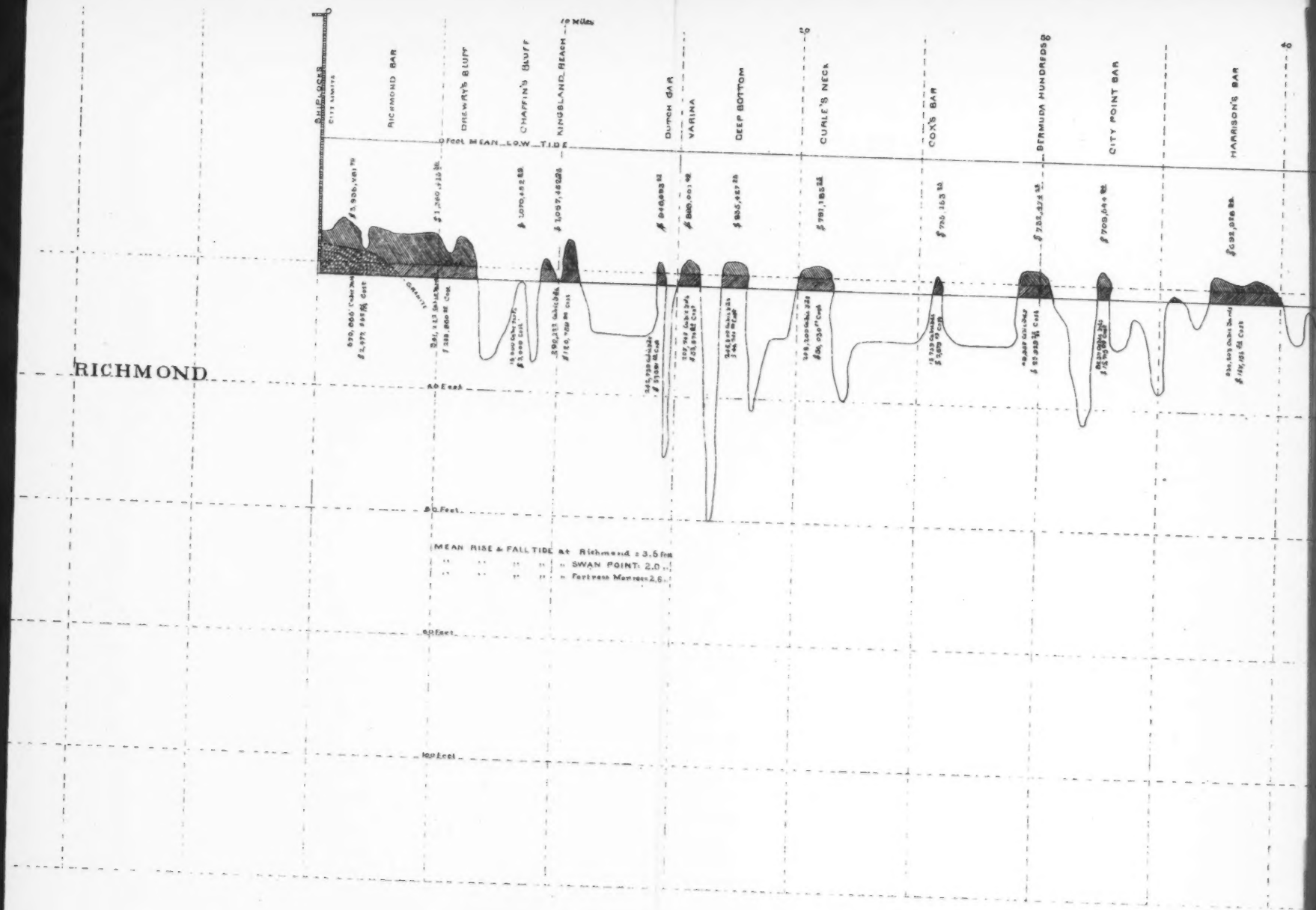

50 Miles
FORT POWHATAN
DANGING POINT
SWAN POINT
GOOSE HILL FLATS
THIBELL SHOAL
ROCKLANDING SHOAL
0 Feet MEAN LOW TIDE
20 Feet
22 Feet at Low Tide
CHANNEL
of
JAMES RIVER VA.
from
RICHMOND to the SEA.
1885

PLATE XXXVI
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XIX Nº 399.
CRAIGHILL ON
ATLANTIC COAST RIVERS.




RICHMOND
0 Feet MEAN LOW TIDE
40 Feet
80 Feet
120 Feet
MEAN RISE & FALL TIDE at Richmond = 3.5 feet
" " " " " SWAN POINT: 2.0 "
" " " " " Fortress Monroe 2.6 "
SHIP YARD
CITY LIMITS
RICHMOND BAR
DRURY'S BLUFF
CHAFFIN'S BLUFF
KINGSLAND REACH
DUTCH GAP
VARINA
DEEP BOTTOM
CURLE'S NECK
COX'S BAR
BERMUDA HUNDREDS
CITY POINT BAR
HARRISON'S BAR
10 Miles
0
40

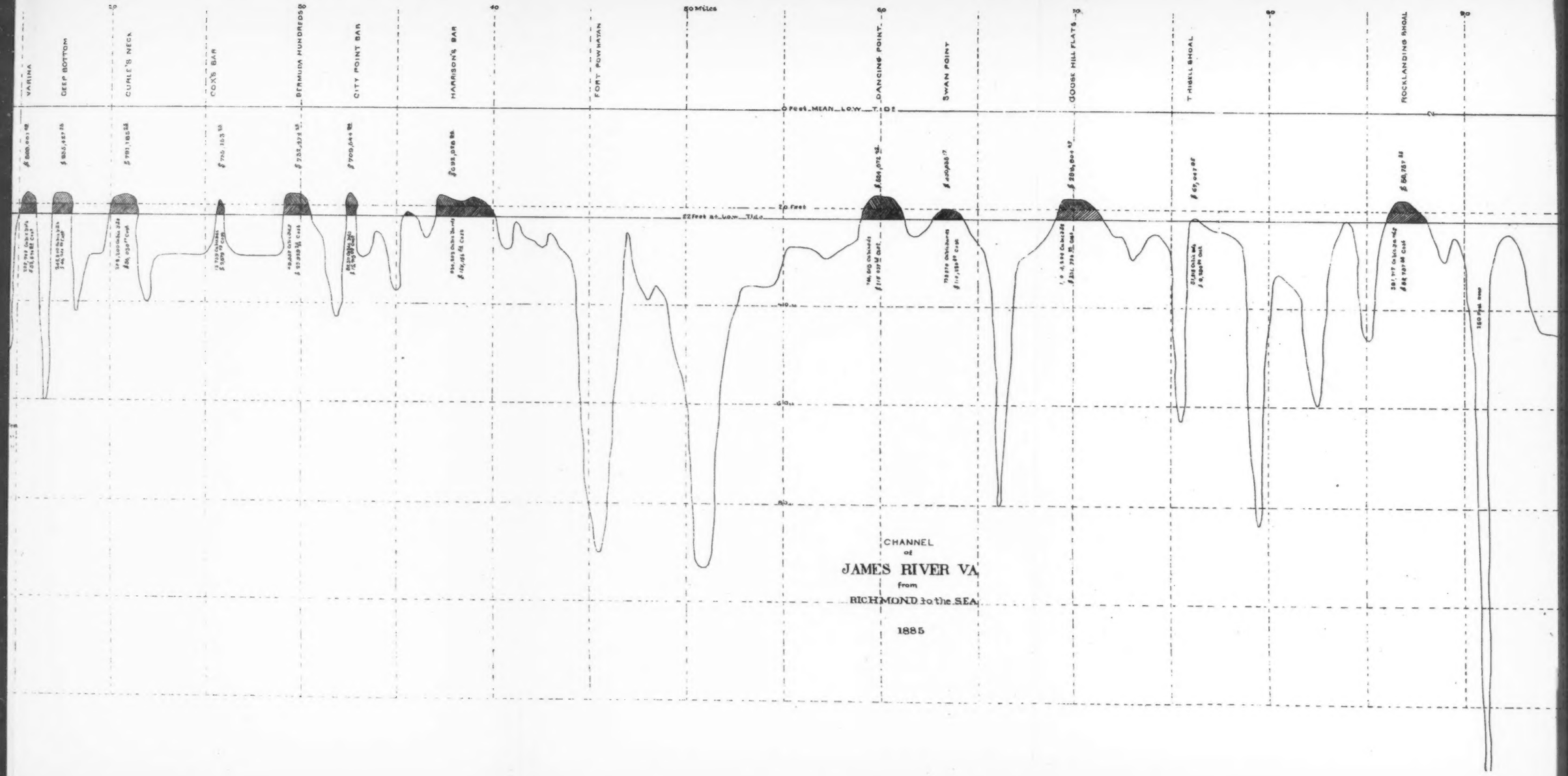
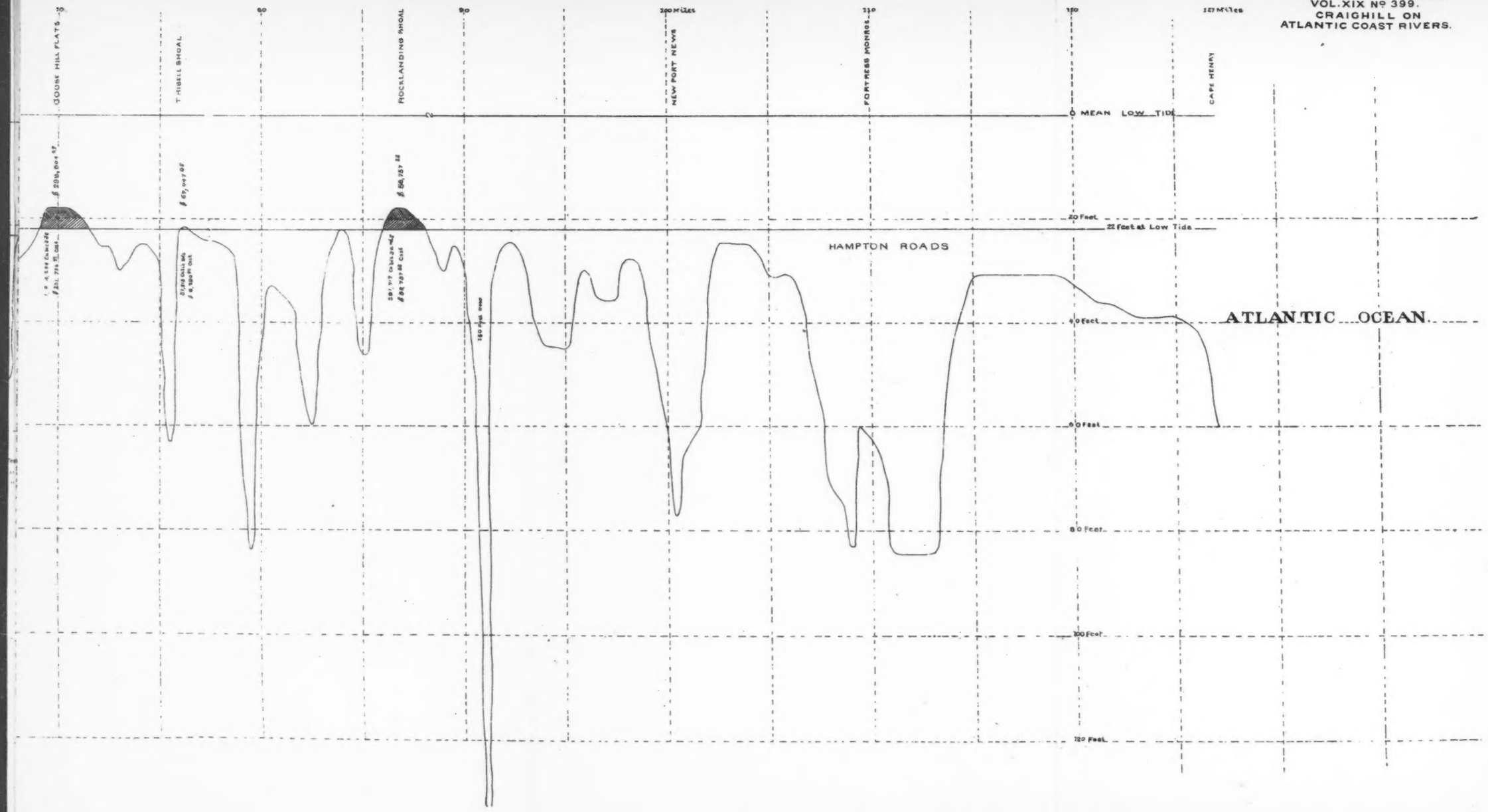
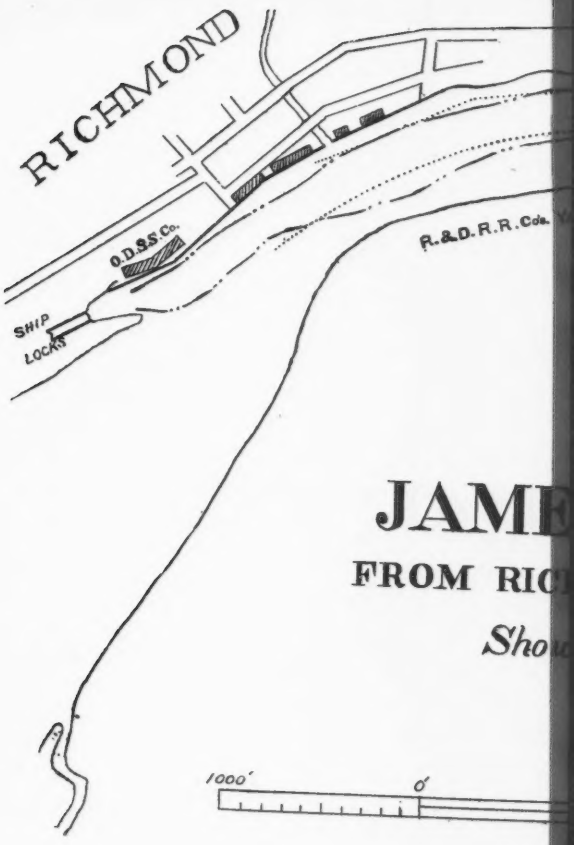

VARINA
DEEP BOTTOM
CURLE'S NECK
COX'S BAR
BERMUDA HUNDREDS
CITY POINT BAR
HARRISON'S BAR
FORT POWHATAN
50 Miles
DANCING POINT
SWAN POINT
GOOSE HILL FLATS
TURKELL SHOAL
ROCKLANDING SHOAL
0 Feet MEAN LOW TIDE
10 Feet
22 Feet at Low Tide
CHANNEL
of
JAMES RIVER VA.
from
RICHMOND to the SEA.
1885

PLATE XXXVI
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XIX Nº 399.
CRAIGHILL ON
ATLANTIC COAST RIVERS.



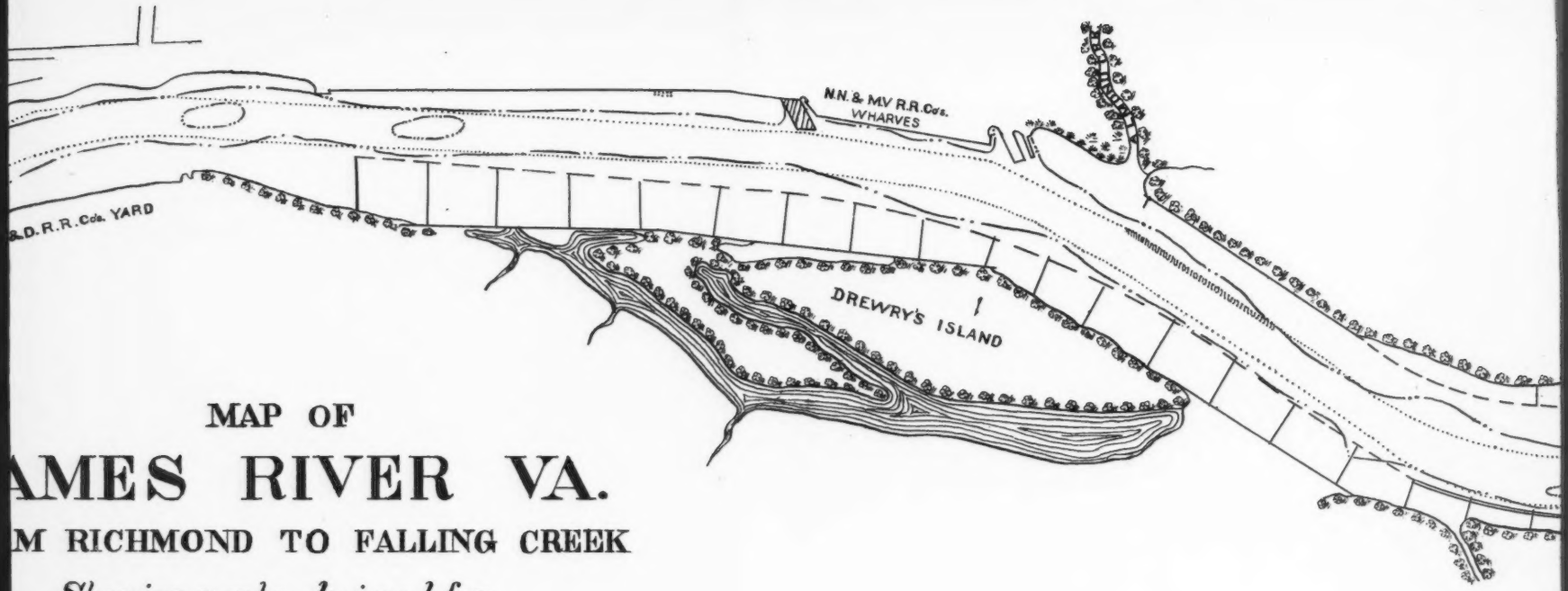


JAME

FROM RIC

Sho

Mean
Longitudina
,,
Wing-dams
Lines of pr
Area dredg
2 fathom co
3 ,,



MAP OF
AMES RIVER VA.
M RICHMOND TO FALLING CREEK

Showing works designed for its improvement.

SCALE

1000 2000' 3000' 4000'

1887.

Note.

Mean rise and fall of tide = 3.5 ft.

ngitudinal dyke proposed shown thus. ----

" " *constructed* " " ═══

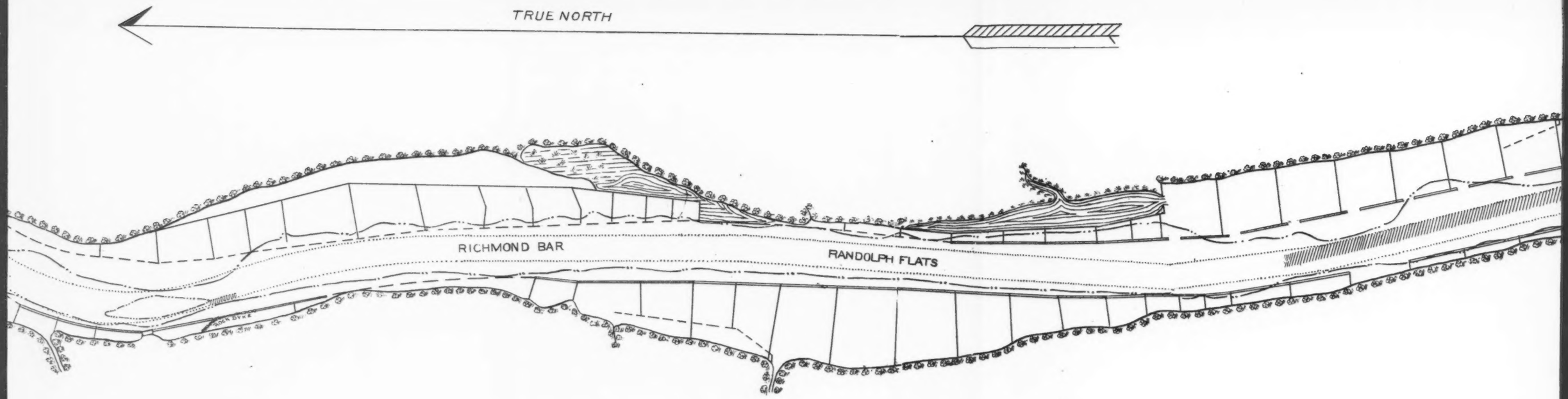
g-dams " " " ———

es of proposed channel " " .....

ea dredged in 1887 " " ////////

athom contour " " —·—

" " " " —···—


TRUE NORTH
RICHMOND BAR
RANDOLPH FLATS

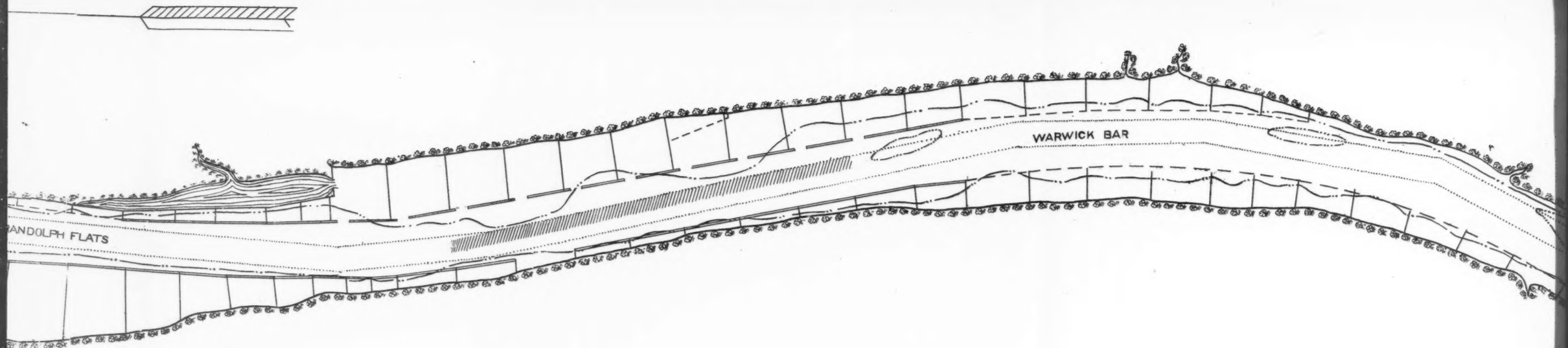

WARWICK BAR
ANDOLPH FLATS

PLATE XXXVII
TRANS. AM. SOC. CIV. ENGRS.
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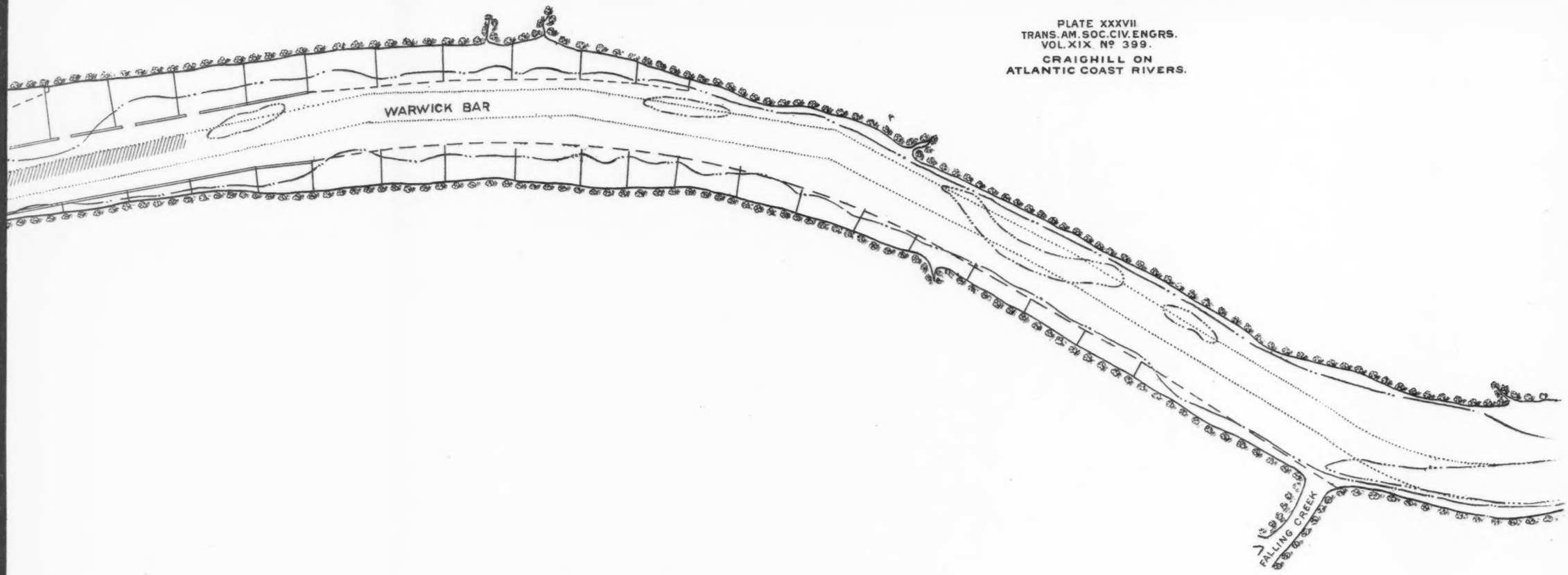
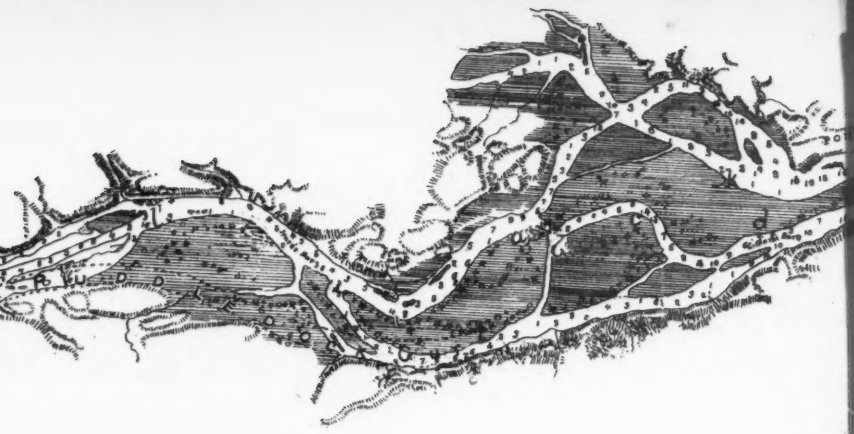
CRAIGHILL ON
ATLANTIC COAST RIVERS.



APPOMATT

Soundings Reduc
Rise and Fall



TOX RIVER, VA.

1855.

SCALE

Statute Miles

duced To Mean Low Water, and in Feet
Fall of Tides 3 Ft

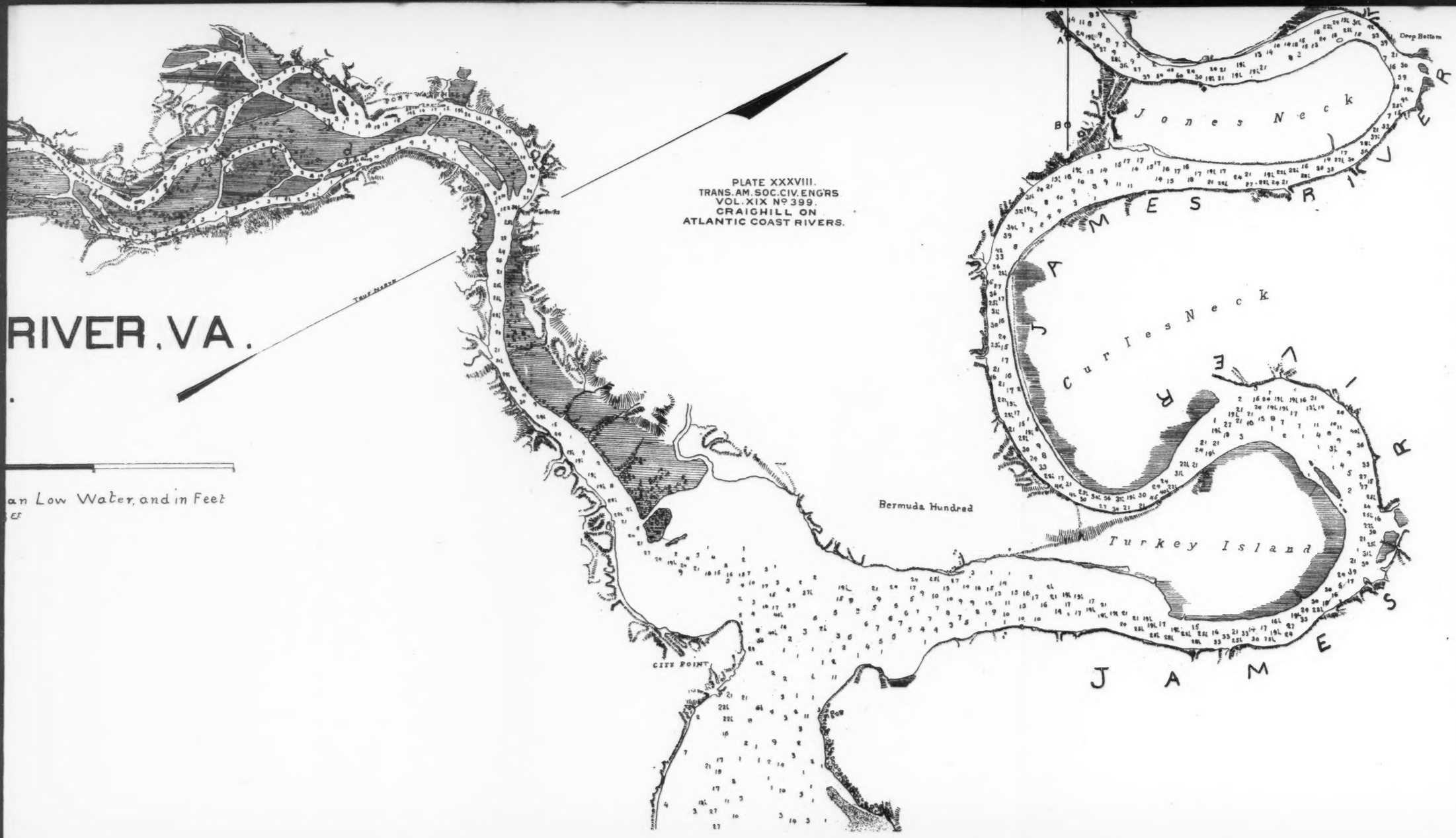


PLATE XXXVIII.
TRANS. AM. SOC. CIV. ENG'RS
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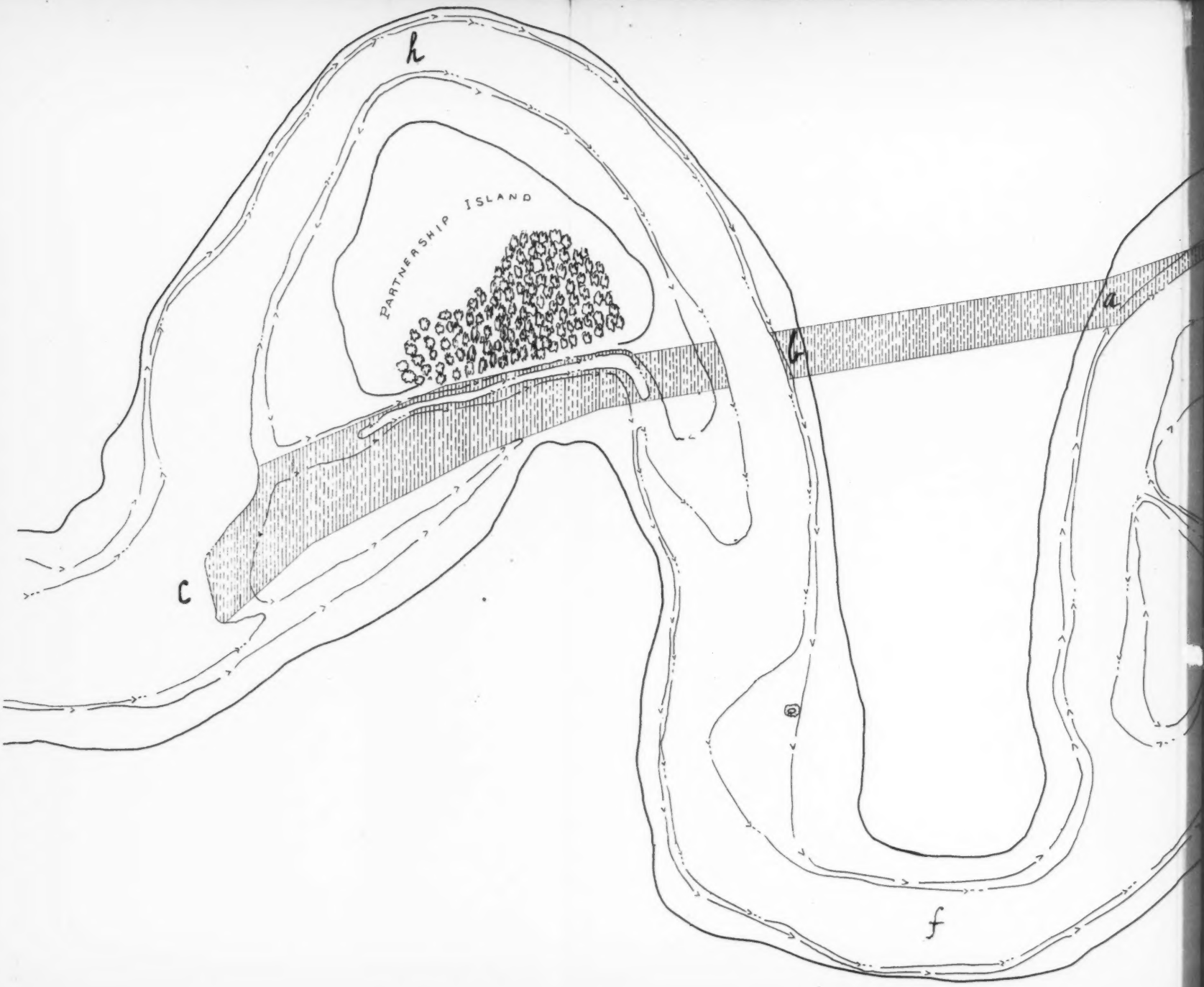
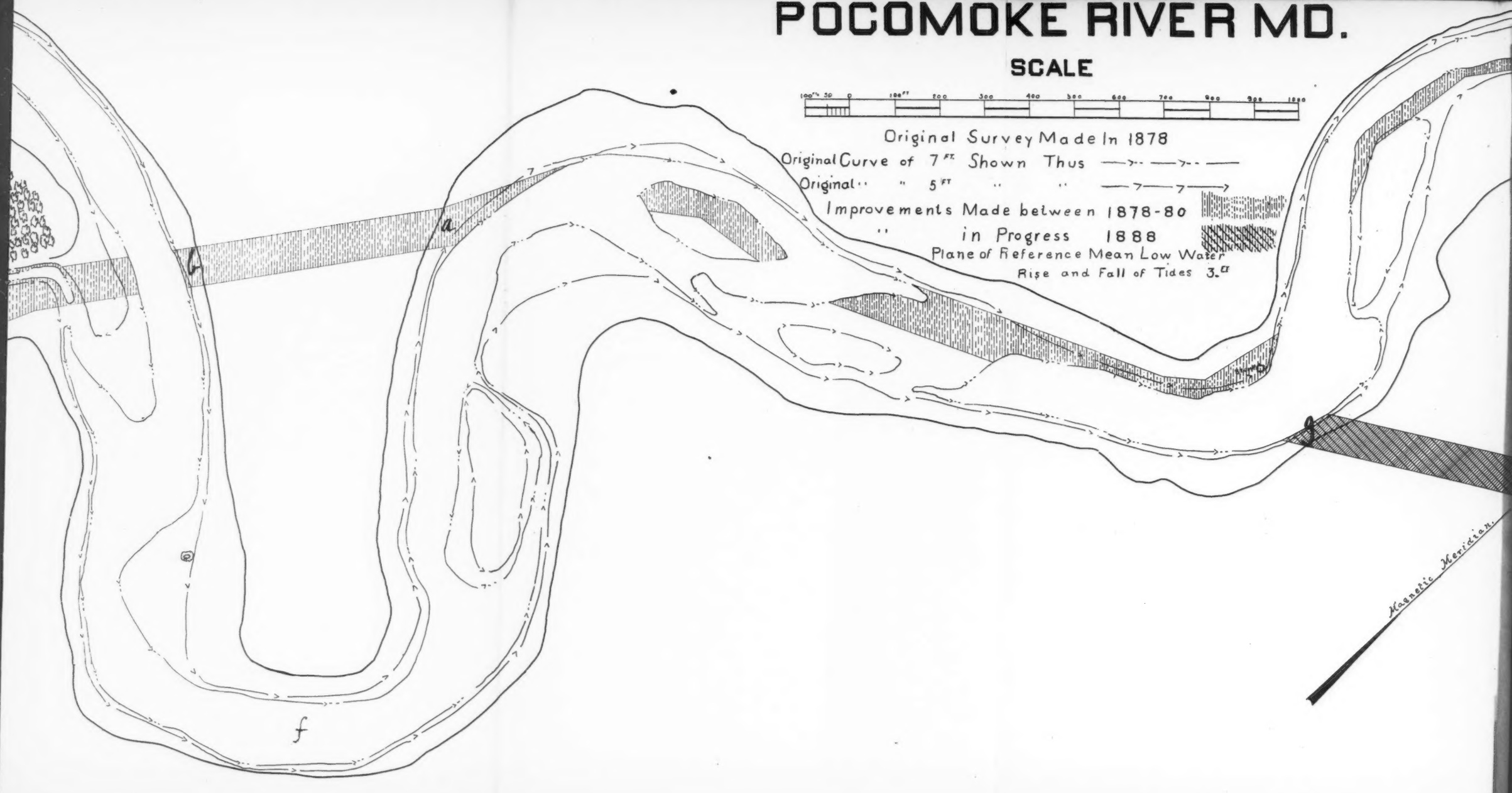
CRAIGHILL ON
ATLANTIC COAST RIVERS.
RIVER, VA.
an Low Water, and in Feet
Deep Bottom
Jones Neck
JAMES RIVER
Curles Neck
Bermuda Hundred
Turkey Island
CITY POINT
JAMES


h
PARTNERSHIP ISLAND
a
G
C
f

POCOMOKE RIVER MD.


SCALE
100 50 0 100 FT 200 300 400 500 600 700 800 900 1000
Original Survey Made In 1878
Original Curve of 7 FT Shown Thus
Original " " 5 FT " "
Improvements Made between 1878-80
" in Progress 1888
Plane of Reference Mean Low Water
Rise and Fall of Tides 3.0 FT
a
b
d
e
f
Magnetic Meridian

POCOMOKE RIVER MD.

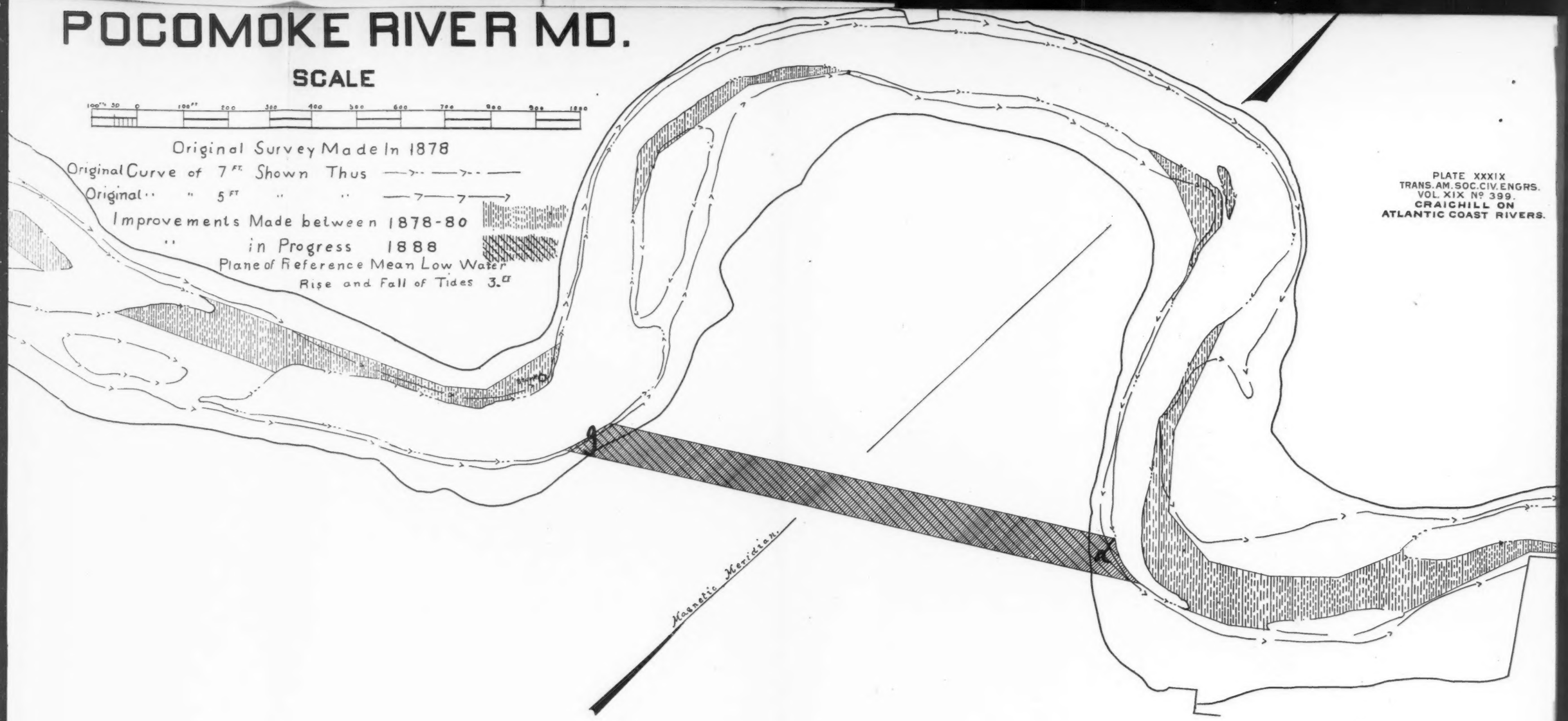

SCALE
Original Survey Made In 1878
Original Curve of 7 Ft. Shown Thus
Original " " 5 FT " "
Improvements Made between 1878-80
" in Progress 1888
Plane of Reference Mean Low Water
Rise and Fall of Tides 3.0
Magnetic Meridian.

PLATE XXXIX
TRANS. AM. SOC. CIV. ENGRS.
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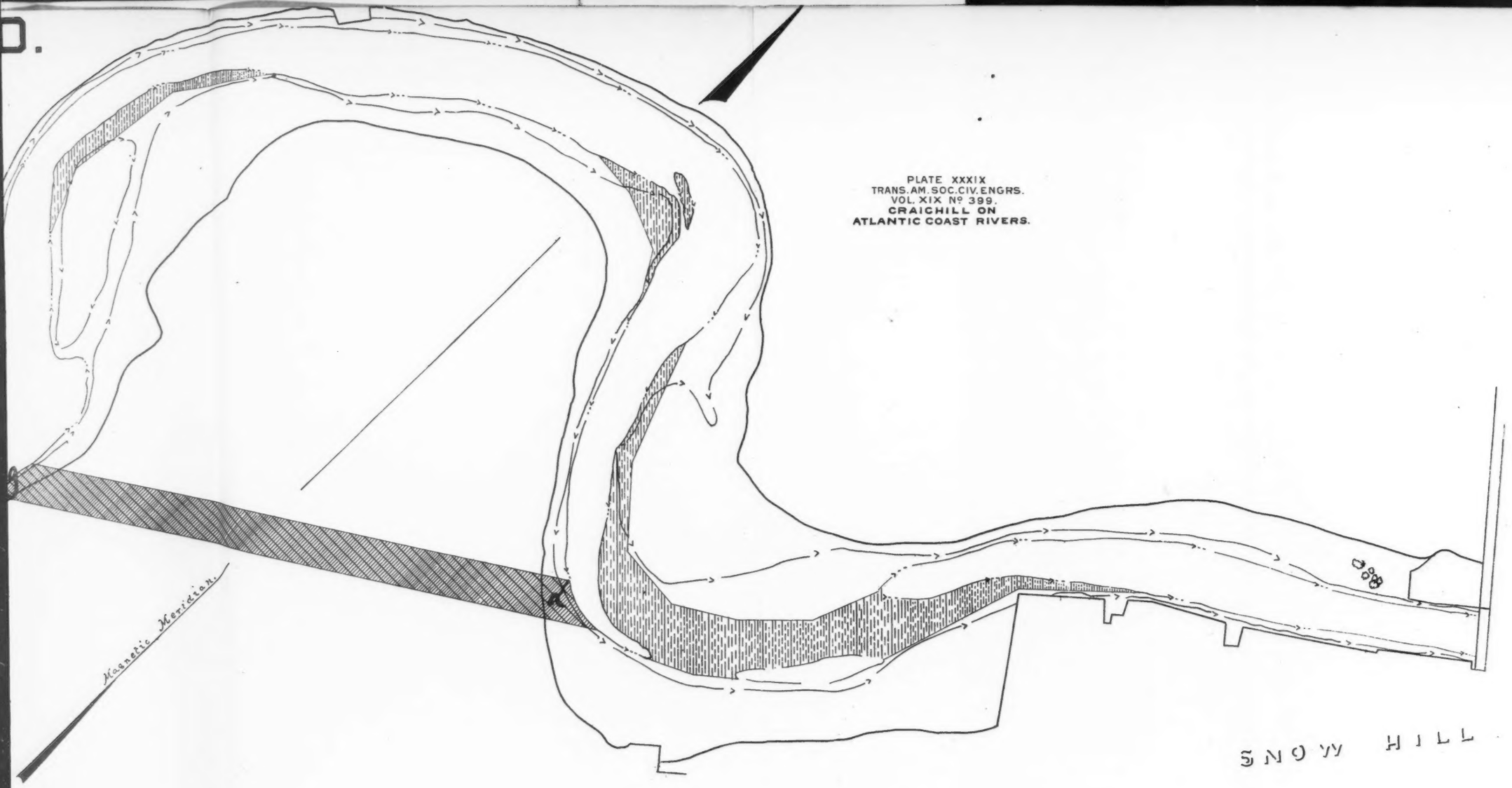
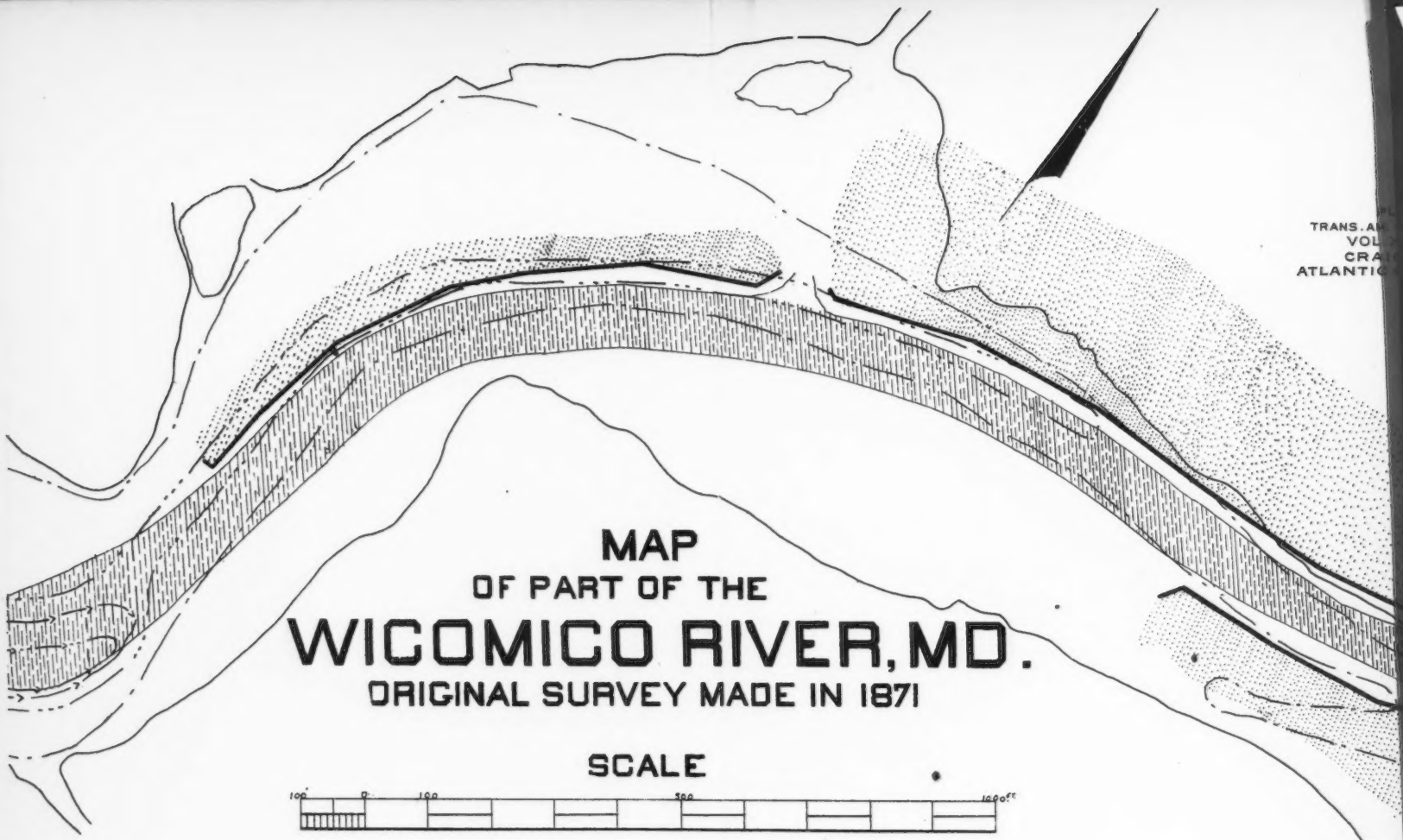
CRAICHILL ON
ATLANTIC COAST RIVERS.

PLATE XXXIX
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIX Nº 399.
CRAICHILL ON
ATLANTIC COAST RIVERS.





MAP
OF PART OF THE
WICOMICO RIVER, MD.
ORIGINAL SURVEY MADE IN 1871

SCALE

Curve of 1 Ft. Shown Thus

" " 3 Ft. " "

" " 5 Ft. " "

Improved Channel Dredged to 7 Ft. Shown Thus

Areas Filled to about 5 Ft. with dredged material Shown Thus

Dykes Shown Thus

Plane of Reference Mean Low Water

Rise and Fall of Tides 3 Ft.

PLATE XL
TRANS. AM. SOC. CIV. ENG'RS.
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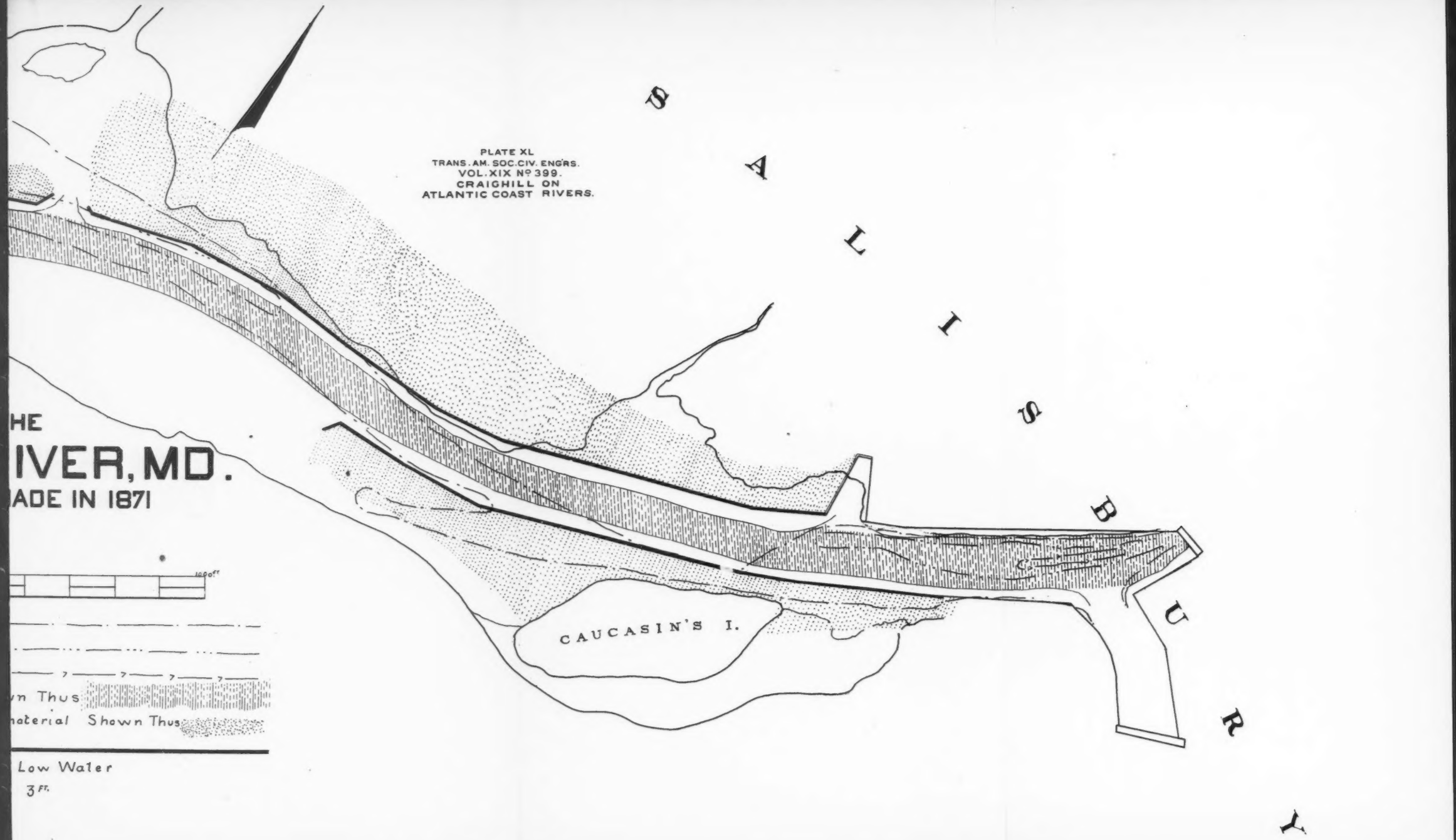
CRAIGHILL ON
ATLANTIC COAST RIVERS.



HE
IVER, MD.
ADE IN 1871

1000 FT

n Thus
aterial Shown Thus

Low Water
3 FT.

of freshets. The promoters of this project are allured by some of its attractive features, but lose sight of serious objections which may be brought against it.

Wicomico River.

This river on the eastern shore of Maryland empties into Chesapeake Bay, nearly opposite the mouth of the Potomac. It is not a large stream, and flows through a flat country; its banks are to a great extent marshy and its bed muddy. Its width is great in comparison with other elements of the regimen.

When the river was examined some years ago with a view to its improvement by the United States, it was found that navigation to Salisbury, one of the largest towns on the eastern shore, was prevented by a bar a short distance below the town, composed of mud, sand and sawdust, on which there was a depth of less than a foot at low water. A gauging of the stream showed that it was capable, with proper treatment, of having a channel 7 feet deep at low water and from 75 to 100 feet wide. Contraction of the width was the remedy with the help of the dredge.

Steps were also taken to prevent the further emptying into the river of the large quantities of sawdust thrown off by the extensive mills of the town. This material, sawdust, soon becomes water-soaked, and falling to the bottom and mixing with the sand and mud makes a tough bar not easily movable by water at low velocities.

The map (Plate XL) shows a part of the area over which the improvement has been carried. A new river has been made. The contracting dikes were cheaply built of the timber of the country, being brought a little above the line of high water. The loss of water through the side channel behind Caucasin's Island was prevented by the dike. The dredged material was placed behind the dikes or in side channels and hollows whence the water was driven into the channel. In some cases the material was troughed 175 feet in the way mentioned in the part of this paper referring to the Appomattox River. The artificial banks have in some parts been planted with willows, etc., and have become well consolidated. The dredged channel has been carried some 3 000 feet below the limit of the map and the material utilized as explained, but, as usual in such cases, there has not been money enough provided for completing the lines of dikes.

It is to be expected that some dredging must be occasionally done in an artificial channel like this (specially while the diking is incomplete), which should be classified as repairs. To such treatment all the works of man are liable. An improvement like this is also most important in increasing the healthfulness of a large community by facilitating the drainage of a wide area of country.

This improvement has been mentioned because it has been one of the localities ridiculed in Congress and elsewhere. The general outline of

the matter is the following: This river has the town of Salisbury at its head. Some years ago no steamboat, and in fact no boat of any size, could reach the town, inasmuch as there was a shoal below it on which, at low tide, there were only about 12 inches of water. Now there are 7 feet, and at high tide 3 feet more. What is the effect of this improvement, which has cost about $30 000? It is to cheapen freights, and bring to Baltimore by a free and natural highway much trade which formerly went elsewhere by an artificial one. Salisbury and the country immediately tributary to it have also been greatly benefited. What benefits Baltimore, a great national seaport, is a thing of national interest.

The method of the improvement of the Wicomico is precisely the same as that employed on the Clyde, in Scotland, on which millions have been expended to give sufficient depth of water for the largest ships, and to this end the dredges have dug through shoals where formerly the depth of water was measured by the inch. In all such cases, where there is an unlimited reservoir of water to be drawn upon, like Chesapeake Bay and the ocean, the depth which can be had is limited only by the amount of money available.

Many persons suppose that the Clyde is a grand, broad river. This is a great mistake. The Wicomico compares favorably with the Clyde as to width, and can be made as deep for a tithe of the money. Some people will say Glasgow, on the Clyde, is a great city, and Salisbury, on the Wicomico, is insignificant. When Glasgow was as young as Salisbury she was quite as insignificant. The greatness of Glasgow has grown with the improvement of the Clyde, and so might Salisbury grow with the Wicomico.

Ridicule has also been cast upon the improvement of Corsica Creek, on the eastern shore of Maryland, by some who never saw it, and do not know that this creek, which might be properly called a river, is actually as large as many rivers in Great Britain and on the Continent of Europe, where millions have been expended for their improvement, and with the most valuable results.

Nobody doubts, I suppose, the propriety of the improvement by the United States of a great river like the Mississippi or the Columbia, but these streams are not great throughout their whole lengths. They become smaller towards their heads. Where will the line be drawn where the general Government shall cease its work of improvement, and who will then continue it? If difficulty be found in drawing such an artificial line, will you reject as a proper subject for improvement by the United States a river that is comparatively small but larger than the upper part of the Mississippi or the Columbia, and which with its connections, the ocean, has a common interstate and European outlet?

Sometimes also we hear sneers at the idea of improving streams of considerable size for the purpose of facilitating and cheapening the

bringing to market of millions of feet of lumber of the most valuable and various kinds. The sneering ones say that logging is not navigation, forgetting or not knowing that the timber which is brought down many streams not navigable by boats is one of the most valuable products for the commercial uses of the whole country. In its movement to a market it has the peculiar property of being its own carrier and does not need the help of any other by land or water.

In truth, an annual River and Harbor Bill of fifteen or twenty millions of dollars is not unreasonably large for such a country as ours, considering its immense extent, its rapid development and other circumstances. Though such a sum looked at by itself without regard to its object seems a large one, it is actually small in view of real needs, and appears almost insignificant in comparison with those of other nations of less extent and population, much of whose wealth and power come from the effects of just such works of internal and coast improvement as such expenditures have allowed.

A number of streams on the eastern shore of Maryland have been improved by the United States after methods similar to that referred to for the Wicomico. One of these is the Elk River at Elkton on the line of the Philadelphia, Wilmington and Baltimore Railroad. This is mentioned here in order to call attention to a detail of which it is the first instance in this section. In 1883 the old regulating dike was found to be so decayed as to require renewal or removal. This dike had originally been built as a bulkhead behind which dredged material might be conveniently placed, and thus prevented from going back into the channel, as well as to contract the water-way. It had always been expected this longitudinal dike of timber would decay at or near the water line, and must then be renewed or removed, or the earth behind it, having had time for consolidation, be sloped back and formed into a new bank for the stream. It had been found also that vessels use the piles of a timber revetment to fasten their lines upon, and frequently pull them over and make a hurtful obstruction. It was concluded, therefore, to remove the old dike and slope back the bank, which was done, and the river was thus left with a new but permanent, though artificial bank.

CONCLUSION.

It had been the wish of the writer to add a brief account of the improvement of the Cape Fear River, but want of time and other causes have prevented. The problem there has been a very interesting one, the main points having been the closure of one mouth of the river, which was about a mile wide, and the use of the dredge and regulating works at other points. The improvement covered a stretch of about 25 miles from Wilmington to the ocean.

The results of the work on the several rivers referred to in the preceding paper may be briefly given as follows:

PATAPSCO.—Improved position, length and width of the channel; increase of depth from 18 feet at mean low water to 27 feet at the same stage.

JAMES.—Improved position, length and width of channel; increase of depth from 7 feet at mean low water to 13½ at the same stage.

APPOMATTOX.—Improved position, length and width of channel; increase of depth from 3 feet at mean low water to 9 feet at same stage.

WICOMICO.—Improved width of channel and increase of depth from 1 foot at mean low water to 7 feet at the same stage.

POCOMOKE.—The object was not an increase of depth but of width and direction, both of which have been attained.

CAPE FEAR.—Improvement in depth on sea-bar from 9 feet at mean low water to 14½ at same stage; increased depth to Wilmington from 9 feet at mean low water to 16 feet at same stage.

The Plates accompanying this paper are:

Plate XXXIV.	Patapsco River and Baltimore Harbor.
" XXXV.	The James River from Richmond to Jones' Neck.
" XXXVI.	Profile of the Channel of the James River from Richmond to the Sea.
" XXXVII.	The James River from Richmond to Falling Creek.
" XXXVIII.	The Appomattox River.
" XXXIX.	The Pocomoke River.
" XL.	The Wicomico River.

DISCUSSION.

F. COLLINGWOOD, M. Am. Soc. C. E.—The paper so unostentatiously put forward by Colonel Craighill is one of general interest to the profession. An engineer never knows how soon he may be called upon to do something in the training and control of rivers, and, therefore, every one should possess at least a general knowledge of this important subject. The several examples described in the paper seem to have been successfully dealt with, and as success is the proof that proper methods have been pursued, they become examples for study and not for criticism. Intelligent criticism, too, is hardly practicable without more of detail than is given.

The leading idea in these works seems to have been the true one, viz., to work with nature, thus economizing effort, and obtaining permanency in the established channels. The fact, for instance, that at Baltimore there was a line on which the flow of the rivers concentrated, where the bottom was at many points too hard for the stream to act upon, all sediment being swept away, led to the conclusion that if the artificial channel were removed to this line, natural forces would keep it open. This reasoning was fully sustained by subsequent results.

So far as I have seen the rivers of Virginia, their tide water reaches are mostly through light, cavy soils, so that the banks are not permanent. The James River, for example, has a width at Newport News of about five miles, of which a wide reach on each side is made up of shifting sands, the water deepening slowly to 9 to 15 feet at the edge of the channel, and then sharply to about 75 feet in the channel. Every year the bluffs cave off more or less, and the material is carried along by wind and wave, requiring frequent dredging to keep a sufficient depth of water along piers and bulkheads. This wear is plainly shown at Jamestown, further up the river, where an earthwork thrown up during the war, in front of the old historic church, has had the front embankment entirely cut away. In traversing an old survey made some fifty years ago, two miles above Newport News, I found some 40 feet had been cut off across the river front.

This being the case, it is evident that the methods pursued in improving the channels must be similar in character to those adopted on the Mississippi; that is, not only to train the stream, but to protect the banks from wash. In the wide reaches the waves are the most active agents of destruction, but further up, where the stream narrows greatly, the currents, doubtless, act most powerfully.

As no details of currents, discharge, or construction of works are given, it is useless to attempt any discussion of exact methods.

The Dutch Gap cut-off is spoken of with approval. The question of permanency cannot be dealt with without fuller knowledge of the conditions of the river at this point.

As to the question of the "tentative" treatment of rivers, it will be remembered that Captain Eads (cited by Colonel Craighill) always held to a very positive treatment. In other words, having made careful observation of all the elements of the problem in hand, he would advocate a bold and radical treatment, as being most likely to lead to success.

As the writer of the paper justly points out, however, the opposite course is almost necessarily pursued by Government engineers, for the simple reason that appropriations are made by piecemeal; and it is impossible to do otherwise than attack the most salient features of a given problem, in the hope that by reaching quickly a measure of success, further appropriations may be obtained. It should be added that no person was more ready to make changes in plans than Captain Eads, should the necessity become apparent in the progress of work.

The remarks about the ridicule and abuse heretofore cast upon some of the schemes for improvement of rivers and harbors are fully justified.* If European governments find it to the general interest of the community to improve rivers and multiply canals in every direction as a means of furnishing cheap channels of transportation to regions otherwise isolated from the trade of the world, we can surely make no mistake in following their example. By our present halting policy we make all such works cost vastly more than they ought. Instead of letting them depend on the cupidity or self-interest of politicians, a system should be devised by means of which the initiation of a work should depend on its importance and urgency, and its progress and management be active and business-like. Having once been decided upon, appropriations for the entire work should be made, and its construction and management should be independent of political intrigue.

C. P. E. BURGWYN, M. Am. Soc. C. E.—In the outset of my contribution to the discussion of the article written by Colonel Craighill on the subject of "The Improvement of Several of the Rivers of the Atlantic Coast," it occurs to me to say that one of the most valuable of the "observations" is that of comparing the treatment of a river by an engineer to the treatment of a patient by a physician.

It is doubtful if a happier analogy could be supplied, and while the brevity of the article forbade going too much into detail, yet the simile could with great propriety be carried still further. For instance, just as a patient needs one kind of treatment for affections of the head, another for the heart, and another for the limbs, the whole treatment bearing a specific relation to the body; so the treatment of one part of a

* For a description of the great changes wrought in the channel of the Clyde, and the immense trade resulting, reference is made to London Engineering of July 27, 1888, for abstracts from a paper before the Institution of Naval Architects by Mr. James Deas.

river should vary from the treatment of a different part, and what would be necessary or proper for one locality might be entirely erroneous for another. Careful study must be undergone, the diagnosis must first be made before the remedy can be applied; but with the advantage to the physician that his mistakes can be concealed by the grave.

One great trouble with the improvement of a river, as Colonel Craighill wisely suggests, is that those in charge of it very often resort to text-books and other sources of theoretical information without studying the river itself. Of course, a reason for this is found in the fact that it has only been within the last twenty years that our rivers and harbors have been studied scientifically and worked upon systematically; and while to the speculating railroad investor, who wishes to see his money turn over at once, twenty years may seem a long time, yet as a matter of fact it is but a short limit for observations to be extended over in order that *all* the physical characteristics may be had as data. Insufficiency of data is as bad as inaccuracy in data. Thus works might be designed to carry all the water in a stream according to information of late times, yet an extraordinary flood might occur, which would destroy not only these works, but, retarded by them, might overflow and ruin regions never overflowed before. Such a flood actually did occur on the James (one of the rivers mentioned by Colonel Craighill) in 1870, when the water rose to 27 feet above low tide—a height ten feet greater than had ever been known positively before; although there was a discredited legend that 100 years ago a flood had reached that great height. Twice since 1870 have these great inundations occurred. Had their re-appearance not been provided for, disastrous results would have followed the effort to control the river. Another instance of the necessity of long study of a river is evidenced by an inspection of the following table:

CROSS-SECTION OF JAMES RIVER AT RICHMOND BAR, FROM JETTY 30 TO JETTY 40.

Date.	Width of River.	Cross-section Area. Low tide.	Greatest Depth.	Average Depth.
	Feet.	Square Feet.	Feet.	Feet.
1874	1 200	6 008	9.2	4.97
March, 1878	590	5 840	11.9	9.90
September, 1878	500	5 544	13.1	11.09
December, 1878	480	5 443	13.2	11.34
March, 1881	470	5 856	15.2	12.46
May, 1882	450	5 776	16.1	12.84
April, 1884	445	5 911	16.3	13.25
June, 1885	445	5 968	16.3	13.41
March, 1887	445	6 028	16.4	13.55
August, 1888	445	6 026	16.4	13.55

It will be seen that in 1874 the river had a width of 1 200 feet, a cross-section of 6 008 square feet, and an average depth of about 5 feet. The width was successively reduced six different times in a period of four years. During this epoch great freshets occurred, large ice flows and various other physical influences were brought to bear, yet in August, 1888, with a width nearly one-third less, the cross-section was three-tenths of one per cent. of what it was in 1874, while there was a gain of over 7 feet in the mean depth. Nothing but a study extended over a long period of time could accumulate these data. The cross-sections were taken by stretching a steel wire across the river, marked at every 10 feet, and sounding with a pole graduated to feet and tenths. The data thus obtained can be considered accurate.

Having collected these facts, the next question is to know whether this same law of constancy of low water areas would hold at different points on the river; how it would be modified by the gradually increasing form of section, which a tidal river must have as you approach its mouth; what would be the effects of curvature, and what should be the curve of the cross-section? Again, how must the section be constructed so as to admit of the discharge of the increased volume of water, when a great freshet is inundating a country, without allowing the velocity to increase to a dangerous degree? Evidently there is much that must and can only be learned by experience.

The great problem of the effect of a cut-off on a tidal river has been carefully studied on the James, and worked out with eminent practical success at Dutch Gap (Plate XXXV). The length of the cut is only 160 yards, yet it saves a long and tedious circuit of 5½ miles, and avoids shoals that had been a great drawback to navigation from the very beginning. When the cut was first undertaken, careful observations were made so as to eliminate all local action, for the mean low water plane was a difficult thing to determine. The area of the cut-off was sounded out, so as to make a future comparison, and as each successive enlargement was made, the same observations were gone over. Finally, after the gap had been worked upon at various intervals for about fifteen years, the entire course of the river has been permanently changed, and the old channel is slowly filling up. Over a million cubic yards have been deposited in the basin. The river goes through an arc of about 180 degrees with a diameter of 1 440 feet.

The effects of making the cut on the height of tide were predicted by the river pilots as about to be most disastrous. They argued it would be like a ditch, that the river above would be drained to a great extent, and that the tides would no longer rise to the usual heights. But, possessed of the accurate knowledge that the various surveys had given him, Colonel Craighill executed the work without regard to ignorant opinion, and its completion justified his confidence in these researches.

As a matter of fact, the cut-off has had a slight effect in raising the

high tide mark at the head of tide-water, and a slight effect in lowering the low tide mark. That is, the range of tide has been increased, but only, however, by a small amount. The "luni-tidal interval" is shorter, while the duration of "stand" is somewhat longer. The great feature of the cut-off, outside of the saving in distance, is the facility it affords for discharging water in a freshet. The usual slope of the river being about 1 foot to the mile in a freshet, it follows that at the Gap there is an amelioration in the slope of from 3 to 4 feet. This benefit is almost inestimable, for sometimes an extra foot of rise means the destruction of a large amount of property. The deposit of a million cubic yards is a serious matter. It will not do to attempt a change in the forces of nature without thorough knowledge. As Colonel Craighill most truly says: "One ounce of experience is worth tons of theory."

When the work of the improvement of the river was commenced, the navigable depth was only a little over 10 feet at high tide. At the present time (September, 1888) it is a little over 17 feet. Under Colonel Craighill's treatment there has been a distinct and positive gain of 7 feet in the practical draft of such vessels as now come to the port of Richmond. Applying the rule that the value of a port varies as the cube of the water depth, and taking 10 feet as the depth when the work was commenced, and 17 feet as the present depth, the value of the improvement will be as 10^3 to 17^3, or about as 1 to 5. To test this value in another way, careful tables were made of the rates on water freights before the improvement was commenced and at the present time. Now, by multiplying this difference in freight rate by the total quantity of freight carried, it has been found out that this product represents the enormous saving of a million and a quarter dollars annually.

Lieutenant O. M. Carter, M. Am. Soc. C. E.—The Savannah River affords an excellent illustration of the importance of the correct regulation of the height of contracting spurs mentioned by Colonel Craighill.

In 1885 two spurs or wing dams, springing from opposite banks of that river, were built for the improvement of a shoal known as the Long Island crossing, over which there was, in the unimproved condition of the river, a low-water depth of 12 feet. Within three months after the completion of the wing dams a 15-foot mean low-water channel, not less than 300 feet in width, was scoured out.

In August of that same year the dams were injured by a cyclone and their crests lowered to an average level of about mean low water. Shoaling immediately began to take place, and, there being no funds available for repair, the river soon reverted to about its original condition.

In 1886 both dams were repaired. The desired mean low-water depth of 15 feet was again obtained by scour, and has since been maintained by the dams.

The fact that the outer part of a wing dam or spur is what mainly does the work of scour, has been taken advantage of upon that river to reduce the length of spurs, in some suitable cases of excessive channel width, by constructing detached spurs. These have been successful, and no scour has taken place between their inner ends and the shore.

When the proper channel width is determined by building spurs and subsequently connecting their channel ends by training walls, as suggested by Colonel Craighill, a far lighter and cheaper method of construction may often be used for the latter than would be possible if no spurs were built.

Although the system of works most suitable for the regulation of any tidal river can be determined only by a study of that particular river, I think that in general upon tidal streams having soft, easily eroded bottoms, training walls, or a combination of training walls and spurs, give better results than spurs alone. The currents impinging against the ends of the spurs scour out pockets of excessive depths there, while between the sets of dams are invariably found shoals of greater or less extent, the river bed being thus very irregular, and ill adapted to the rapid transmission of the tidal wave and to the filling of the tidal basin in the upper reaches of the river.

Supplementary remarks to paper of Colonel W. P. Craighill on Improvement of the Rivers of the Atlantic Coast.

Captain William H. Bixby, M. Am. Soc. C. E.—The remarks of Colonel Craighill interest me very greatly, especially because they concern streams similar to those upon which I have been busied for the last four years. The experience of these years leads me to confirm most, if not all, of Colonel Craighill's remarks.

In the regularization of such streams I have found the same necessities for treating each according to its own peculiarities. The best examples of regularized streams are undoubtedly to be found in Europe, but European practice cannot be strictly followed in the United States because of many reasons. In Europe, time, money and private authority or license are of less consequence, and perfection of work is of greater consequence, than in the United States. In my opinion the best engineering is not always that which gives the most perfect results; but the best engineering is rather that which gives the best and most useful results per dollar of expenditure. Had all the money ($47 000) voted by Congress from 1880 to 1887, for the improvement of the Great Pedee River, S. C., been spent in doing perfect work from the mouth of the river upwards as far as the funds would have allowed, the river might have possibly been thoroughly cleared over a third of its distance, and a commerce of perhaps $400 000 per year might have been thereby developed; but by doing rough work over the full length of the river, a commerce of $2 000 000 has actually been brought into existence. Such cases as this are valid arguments for oftentimes doing rapid, though rough and imperfect, work, even though this work may have to be all done over again at some later period. Such work is often the determining element in the development of a colonization and commerce that nothing will ever stop. The necessity for giving to the United States the worth of its money is merely the statement in other words of the idea of advantageous and economical engineering which Congress requires from its engineers. It is this kind of engineering which suggests the use of cheap materials in such portions of regulating works as will be immediately silted up under the action of river currents; which gives rise to much of the so-called tentative engineering; which puts work in roughly at first, to be finished more leisurely at some later moment; which does work only at the places where it is most immediately needed; which allows one bank of a river to take care of itself, not because it would not be benefited by assistance, but because other places need help more than it; and which even uses a dredge to-day although tolerably certain that the dredging may be all filled up again at some later period, though not before navigation has been benefited in proportion to the money expended.

Another point, which may be deduced from Colonel Craighill's re-

marks and which has been fully confirmed by general experience, is that rivers are generally very difficult to drive while often very easy to lead. In other words, it is very important to examine carefully the individual characteristics and local peculiarities of each river before commencing to prescribe its regularization works, in order to know where the river would naturally go if unhampered by obstructions, and in order to make the regularization works conform as much as possible to the natural route and circumstances of the river currents. Where leading is possible, it is generally far more economical to lead; but where leading is impossible, and driving is necessary, the force must be applied with steadiness and power.

I find that the people living on the rivers of the South Atlantic are always very desirous of making short cut-offs across the natural loops of these rivers without having for a moment considered the natural results of such cut-offs, in the increased velocity at the cut-off and the diminution of depths above the cut-off, which usually accompany the opening of such cuts upon up-country steep-grade streams. Moreover, most cut-offs turn out to be more expensive work than at first estimated. The objections to cut-offs naturally decrease with the grade of the river-bed and the approach to tidal and flat neighborhoods.

As Colonel Craighill states, many people are inclined to throw ridicule upon the improvement of streams which bear the name of "creeks." They forget that the greater portion of the South Atlantic creeks would be called rivers in the Northern, Eastern and Middle States and in Europe. After going up some of these creeks on freight steamboats for forty or more miles, and after having found several hundred thousand dollars' worth of goods shipped annually over them, I have gained a new respect for the term "creek," and have realized that all does not lie in a mere name.

Colonel Craighill states that it had been his wish to add a brief account of the improvement of the Cape Fear River, but that want of time and other causes had prevented.

As I have been in charge of this work for a few years as Colonel Craighill's successor, I feel qualified to speak upon the improvement of this river, and I do so with much pleasure.

The two branches of the Cape Fear River meet at Wilmington. They bring down to Wilmington a fresh-water discharge of about 500 cubic feet per second on an average during the three low-water months, and about 18 500 cubic feet per second during the nine flush-water months, or about 14 000 cubic feet per second on an average throughout the entire year. At Wilmington the river has a cross-section of about 14 000 square feet, so that the height of its water surface at this point remains approximately unaffected by the variations in the amount of the fresh-water discharge. Both branches are subject to tidal influence for a distance of about 30 miles above Wilmington.

From Wilmington to the ocean, 26 miles, the Cape Fear River is a tidal basin of about 37 square miles area, in which the tide rises and falls about 2.5 feet at Wilmington and 4.5 feet at the ocean, or about 3.5 feet on an average. At the river's mouth, 1.25 miles wide, the amount of water which must pass to and fro each tide is therefore about 160 000 cubic feet per second. The ocean bar is about two miles to the seaward of the throat of the river's mouth. (See Plate XLI.)

The improvement of the Cape Fear River below Wilmington has been under the consideration either of the State of North Carolina or of the United States since 1821.

Prior to 1761 the Cape Fear River was reported as allowing vessels of 14 feet draught to pass over its main bar at low water and to enter the river by the same route as they follow to-day. In 1761, however, during a violent equinoctial storm of four days' continuance, the wind and sea made a breach, reported at first as 18 feet deep at high water, and later as not over 2.5 feet deep at low water, and nearly half a mile wide, through the sand banks into the Cape Fear River about 8 miles above its former bar entrance, at a place called Haulover. This breach, cutting off 6 miles of the river's length, gradually increased in importance so as to form a new mouth to the river, deepening from 6 feet at low water in 1797 to 10 feet at low water in 1839, and received the name of New Inlet. The effect of this new mouth upon the river was to diminish the depth of water upon the main bar entrance from 15 feet in 1797 to 9 feet in 1839.

The past and present condition of these bars is shown in the following table, the depths being expressed in feet and being (according to the best attainable information) reduced to low water.

Name of Author of Map.	Date.	Main Outlet.		New Inlet.
		Baldhead Channel.	Rip or Bulkhead or Shoalest part of Western Channel.	
Edward Moseley	1733	14	3	Closed.
William Nimble	1738	16	4	Closed.
Joshua Potts	1797	15	3	6
Colonel Kearney, Topographical Engineers.	1820	10.5	3	6.5
Captain Glynn, United States Navy	1839	9?	9	10
Pilots and others	1850	8	9.5	7
Coast Survey, Captain Mallit	1851	8	7	8
" "	1852	7.5	7	8
"	1866	8	8	7.5
"	1871	6.5	8	8
"	1872	8	8	8
"	1877	9.6	7.5	8
United States Engineers	1883	14	7.5	Closed.
" "	1885	14	7.5	Closed.

Prior to the opening of New Inlet, and even until 1839, Baldhead Channel was the natural and main entrance to the river. From 1839

to 1872 both the Rip and New Inlet were the main entrances, and the use of Baldhead was discontinued. Since 1872, and the closure of the New Inlet, Baldhead has again become the main channel, and has been gradually regaining its former depths.

In 1821, the date of the first detailed survey of the river, vessels of over 10 feet draught were obliged to lighter their cargoes 14 miles below Wilmington, 10 feet draught at high water, and 7.5 feet draught at low water, being all that could be carried from the point of lighterage up to Wilmington.

From 1821 up to 1829 the improvement was under the charge of the State of North Carolina. From 1829 up to the present time the improvement has been under the United States.

Between 1822 and 1829, the State of North Carolina, under the guidance of Mr. Hamilton Fulton, State Engineer, attempted to improve the channel between Wilmington and New Inlet by dike closures of the minor channels, by jetty contraction of the main channel-way, and also by dredging across the shoals. A small amount of money (supposed to have been from $60 000 to $80 000) was spent in this way, with moderately good results. This work deepened slightly the water in the main channel and was of especial value as being the commencement of an important river improvement.

By the dikes and jetties thus built, the river currents were restricted in general to a single route; and such scouring as thereafter occurred resulted in a permanent gain in channel depth. One of these dikes, however, that between Big (or Campbell's) Island and the mainland on its west, was expected to force the current to scour a channel east of that island; but this scouring took place very slowly, and the expected results were not finally attained, because of the existence in the desired channel-way of a large quantity of apparently unsuspected logs and stumps. These logs and stumps have had to be removed since at great expense.

In 1826–27 the United States Engineers made a careful survey of this portion of the river.

In 1829, when the United States took entire charge, there were several shoals with a least depth of 7.5 feet at low water between New Inlet and Wilmington.

From 1829 to 1847, by a continuation of the dredging and jettying, in general accord with former work, the depths on the shoals were increased by about 2 feet, so as to allow 9.5 feet at low water, a depth equal to that at the bar entrances.

By 1874 it was evident that the depth on the bar would soon be increased; and therefore under the direction of Colonel Craighill plans were made to deepen the river channels proportionately. The projects of Colonel Craighill of 1874–81 as continued to date proposed: 1st, to locate channels in such positions that the natural flow of the river cur-

rents would thereafter tend continually to keep these channels scoured to full depth; and, 2d, to obtain these channels by dredging and the removal of the before-mentioned logs and stumps. This work has been continued from 1874 up to the present year as fast as possible under the inadequate yearly appropriations of Congress. The results have been eminently successful; so much so that to-day there exists a continuous channel of 16 feet depth at low water over the whole 20 miles above New Inlet. The latter depth, combined with the average rise of tide on the bar (4.5 feet) and at Wilmington (2.5 feet), gives to-day a good 18-foot navigation at high water from the ocean to Wilmington. These channels will probably be completed to 270 feet width and full depth under the present appropriations; and it to-day appears probable that these channels will then remain permanent without the aid of further diking, jettying or dredging. In almost all cases these channels were located along the thread of the supposed natural current.

The lighterage, formerly a necessity over 14 miles of the river, is now entirely given up, and all vessels that can cross the outer bar proceed directly to Wilmington to unload. So far as possible all the work of improvement has been done by contract.

In several parts of the river below Wilmington, at places 2 000 feet from the shore and where there is now 14 feet depth of water, stumps of trees, pine as well as cypress, have been found firmly imbedded in the river bottom in an erect position, apparently surrounded by the soil in which they originally grew. Several theories have been advanced to account for these strange facts, such as that the ground has subsided, or has been undermined since the death of the trees; but none of these theories are entirely satisfactory. Many of these stumps had to be removed; and in their removal the clam-shell dredge developed a remarkable efficiency for such work, rendering the use of explosives almost unnecessary.

In 1829, when the United States Government assumed active charge of the improvements, the river had three bar entrances with least depths about as follows: 9 feet at the Baldhead Channel, 9 feet at the Rip Channel (both near the old river mouth), and 10 feet at the New Inlet Channel; these bars being, respectively, 9, 6 and 2 miles below the point which was then the head of the river's delta. No appropriations were made for work at the river's mouth until 1852, when Congress voted $160 000 for this purpose. Under these appropriations it was proposed to build a dike, 4 400 feet long, across the openings in Zeke's and Smith's Islands on the south side of New Inlet, so as to stop this inlet from growing larger and to check the outflow of water by this route; and it was also proposed to build a jetty at Baldhead Point, to check further widening of the Cape Fear main outlet. All this work was completed as far as the funds allowed.

The jetty, 300 feet long, constructed by Captain Woodbury in 1853

at Baldhead Point, has remained in tolerably permanent condition up to to-day (1885), although its shore end was flanked by the sea in 1871, and although it now stands under water and nearly 1 500 feet in advance of the present shore-line. Between the jetty and the shore the water still remains quite shoal. This jetty was originally built to protect Baldhead Point against further and rapid erosion by the waves and currents. It appeared to accomplish that object until 1870, the date of commencement of work at New Inlet. Its effect, if any, upon Baldhead and the Rip Channel, cannot be stated with certainty.

The closure from Zeke's Island eastward to Smith's Island was attempted by means of a continuous line of very heavy stone riprap, efforts being made to assist the rapidity of the construction by the temporary use of auxiliary perpendicular jetties or piles, sheet-piles, brush, and sand-bags. When it was nearly completed, the specially violent storms of 1857 destroyed the work beyond repair by the funds then available. Subsequent experience in work of similar nature at the same locality leads to the belief that this failure was due, not to the method, but only to the small amount of stone allowable by the moneys then available.

The work of 1852-57 around New Inlet was tentative, and though not permanently successful, was valuable as indicating a solution suggested by the Board of 1853 and recommended by that of 1858, viz., the closing of the minor and accidental outlet, and the concentration of the main volume of the river outflow into the original and natural main outlet.

When further appropriations became available in 1870, and under the direction of Colonel Craighill, in 1870 to 1873 it was decided to completely close New Inlet, to reconstruct the demolished dike along the south side of the Inlet and thus force the entire river discharge through its old route *via* Baldhead channel; and it was decided also to assist the scour on Baldhead Bar by dredging.

The reconstruction of the dike on the south side of New Inlet, from Zeke's Island eastward to the north end of Smith's Island, was made of a continuous line of wooden cribs loaded with smaller stone. The cribs with vertical sides were used from motives of economy to avoid the necessity of excessive side slopes of stone-work, timber being cheap and stone expensive in this locality. The entire dike closure, 4 403 feet in total length, which was not actually commenced until the fall of 1870, was finished in 1873, at an approximate cost of $60 per linear foot, and with great success. The sand has filled against it to such an extent that it is now, for the greater part of its length, several hundred feet distant from the water at high tide. The construction of this dike was a necessary preliminary to the closure of New Inlet.

As another preliminary to the closure of New Inlet, an experimental deflecting jetty was commenced and built a short distance at the point

where the river current turned from the Cape Fear towards New Inlet. This deflector, built of wooden cribs filled with stone, was continued a short distance only, and then it was decided to make this deflector form a portion of the final closing dike across the Inlet.

The experience gained in the construction of the above dikes and deflectors showed the danger of scour (occasionally 12 feet deep) under loaded cribs with solid bottom, and around the advancing ends of dikes in process of construction, especially if the cribs or dikes are raised at first to full height. It showed also the advantage of open bottoms for such cribs. It indicated the method later used in the closure of New Inlet, viz., the use at first of mattress foundations, and low submerged riprap dikes entirely across the place to be closed, to be followed afterwards by a gradual elevation of the entire dike, commencing always at the shore ends. It showed also the ease with which sand banks can be raised several feet by planted sea oats, by catch fences and by brush, and at the same time the necessity for further protecting such artificial banks against subsequent high storm tides and waves.

The work upon the final closure of New Inlet (commenced in 1875 and finished in 1881) deserves especial note, as it resulted in such complete success.

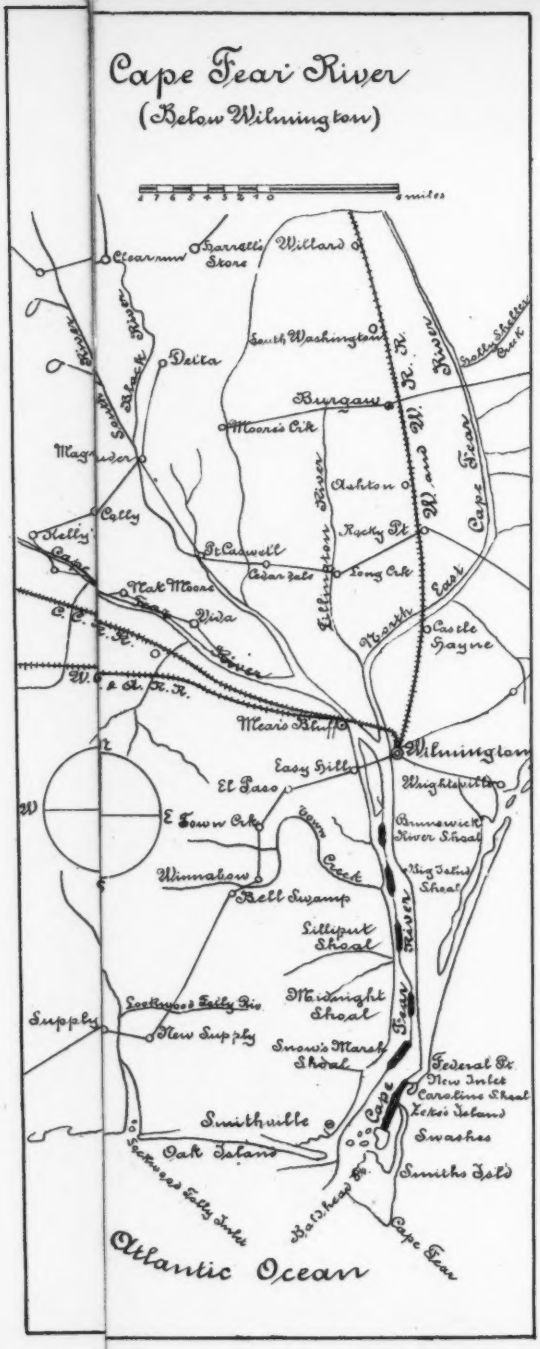
This closure was made of moderately small stone riprap, laid originally on log and brush mattresses, and capped with carefully placed heavy stone (weighing from ½ to 4 tons per piece); the small stone (one-man-stone) being used from motives of economy, and the large, heavy stone being used as a protection against storm waves. The log and brush mattresses were used from a desire to utilize the materials of the country, and because they were one of the elements of cheapness in the bid of the successful contractor. These mattresses were made of pine logs cut in the creek near at hand, formed into rafts of proper dimensions, loaded with as much pine brush as they would carry, towed directly to their places, and sunk by stone thrown upon them from scows. The middle portion of the dam (a length of 3 600 feet) is from 75 to 120 feet broad at its base, and is on an average of 37 feet high; its side slopes are 1 on 1.5 in the river side, and 1 on 2 in the ocean side. The whole dam is 4 800 feet long, contains about 182 821 cubic yards of material, and cost, complete, about $498 000, or about $105 per linear foot, or $2 75 per cubic yard. At present there is a difference often of 2 feet and sometimes of 3.4 feet between the water levels of its river and sea side. During the construction of the dike the scour around its base, due partly to the river current and partly to the over-fall, was so considerable, and the attacks of the teredo were so severe, that the log and brush foundations were to a great extent undermined or eaten up; in consequence, continual additions of stone riprap became necessary, so much so that practically the resulting foundations consist to a great extent of small stones. In view of this later experience it would seem that the

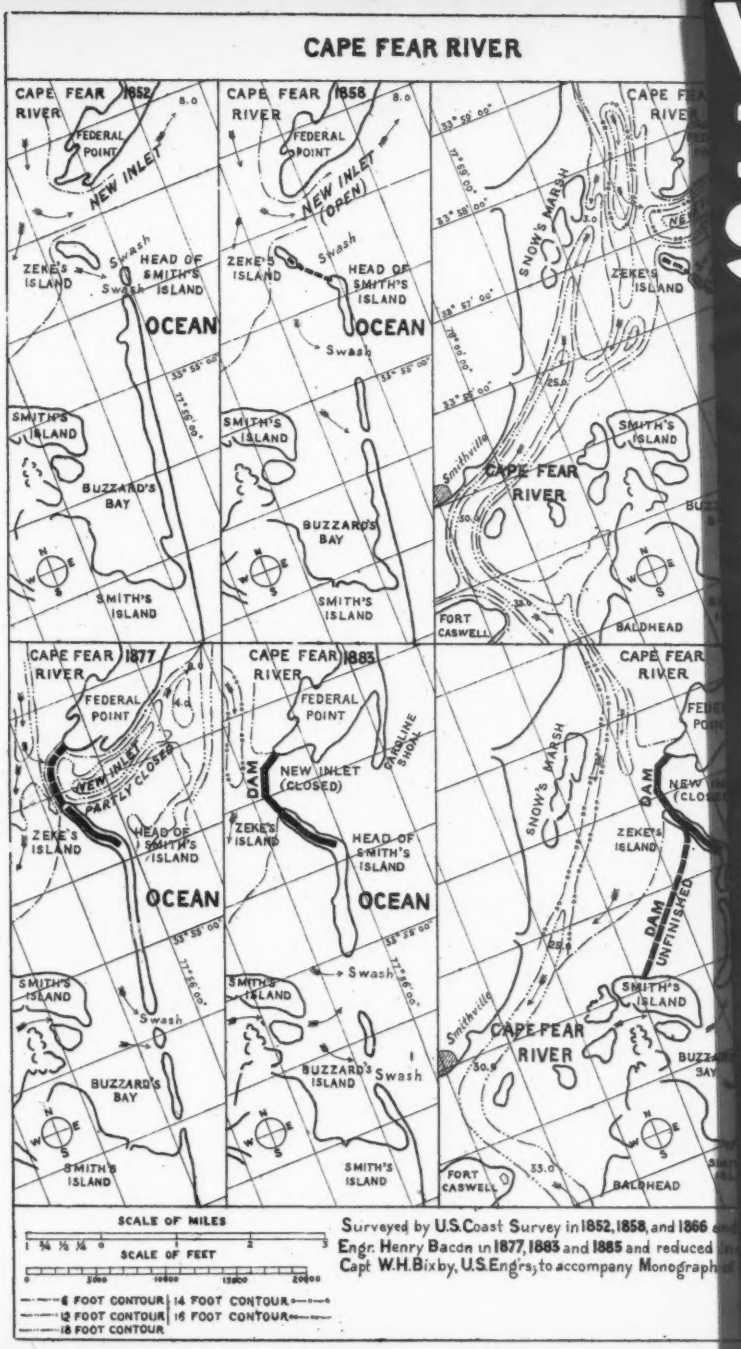
use of small riprap stone foundations from the commencement might have been simpler, quicker, more efficient and cheaper than the use of the log and brush foundations, although the latter were originally suggested by motives of economy.

By the closure of New Inlet (combined with the preliminary closure from Zeke's Island eastward to the ocean beach of Smith's Island) the former coast line was re-established; a shoal, 1.5 miles long and several hundred feet broad at high water, gradually built itself up completely across the old bar entrance of New Inlet; and at the mouth of the river the old channel gradually scoured out to 14 feet depth (against 9 feet depth in 1875).

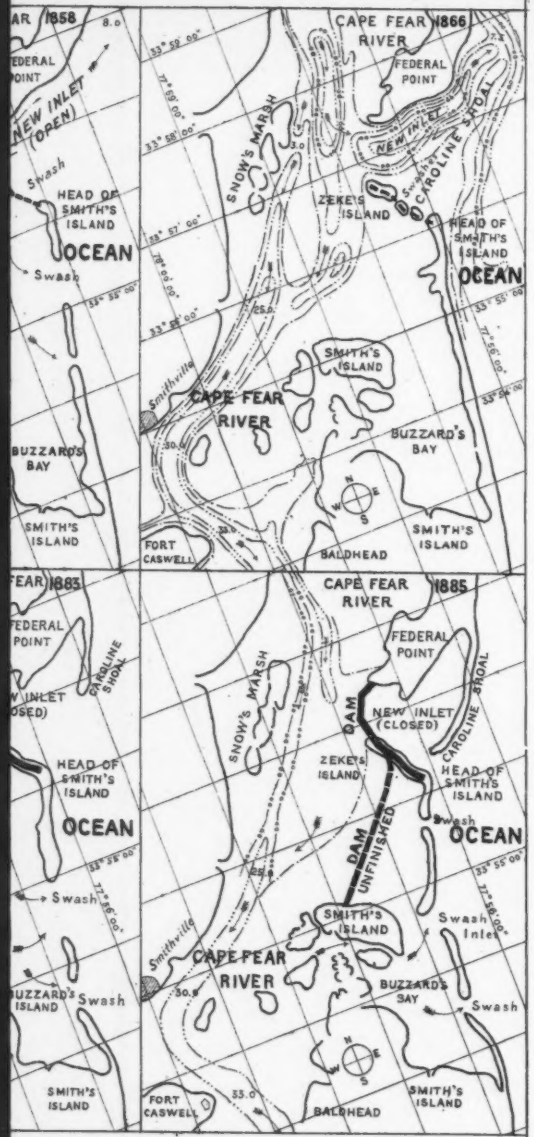
As soon as New Inlet was closed, the river sought to flank this work by crossing over to the ocean south of the closure; and a new dike from Zeke's Island, southward to the south part of Smith's Island, was the natural sequence of the work just described. A first experimental attempt was made, at one of the openings through the strip of sand beach next the ocean, to make the ocean side of Smith's Island continuous by an inexpensive work of round piling, sheet piling, sand bags and timber just in rear of the openings through the beach. A gale arising before the completion of the closure, the width and depth of the opening were so much increased that further attempts to complete the closure in this way were abandoned. The result of this unsuccessful experiment suggested the subsequent construction of a stone riprap dike closure along the neutral line between the ocean and the river, about 1.5 miles in rear of the ocean beach. This new closure, commenced in 1883, and already raised to above low water level, is so far successful, and points to results similar to those that followed the closure of New Inlet. This dike, 11 600 feet long and 7 feet wide on top, rests almost everywhere on a brush mattress foundation, in from 5 to 12 feet of water. The brush mattress was built in sections, each 60 (or less) feet wide, 2 610 (or less) feet long, and 12 inches in final thickness, and cost in place about sixty-six cents per square yard, or $2 65 per cubic yard. The mattress is loaded with 74 000 cubic yards of stone. The dike (foundation included) has cost about $200 000, or less than $18 per linear foot. It rises to the height of high spring tides and has a side slope of 1 on 2. The completion of this new dike (together with the closure of New Inlet) has rendered unnecessary the maintenance of the old dike eastward from Zeke's Island direct to the ocean.

During the progress of the closure of the Inlet, Colonel Craighill decided to hasten and assist the natural scour of the river on the Baldhead Bar. For this purpose, in 1873 and 1874 a steam propeller (Woodbury), of 145 tons burden, was fitted up as a suction dredge (with a double oscillating 10-inch cylinder engine, driving a 9-inch centrifugal pump, and with sand-bins of 40 cubic yards capacity), and proved so successful that it dredged sand in 8 to 14 feet of water upon the bar


Cape Fear River
(Below Wilmington)
Clearmm
Barnett's Store
Willard
South Washington
Delta
Burgaw
Moore's Crk
Ashton
Kelly Pt
Long Crk
Castle Hayne
Wilmington
Mears Bluffs
Easy Hill
El Paso
Wrightsville
Brunswick River Shoal
Big Island Shoal
Winnabow
Bell Swamp
Lilliput Shoal
Midnight Shoal
Snow's Marsh Shoal
Federal Pt
New Inlet
Caroline Shoal
Zeke's Island
Swashes
Smiths Isld
Supply
New Supply
Smithville
Oak Island
Sheppard's Folly Inlet
Bald Head Pt
Cape Fear
Atlantic Ocean
Black River
Cape Fear River
W. & W. R. R.
Wards Creek
Eagle Island
Shelter Pt

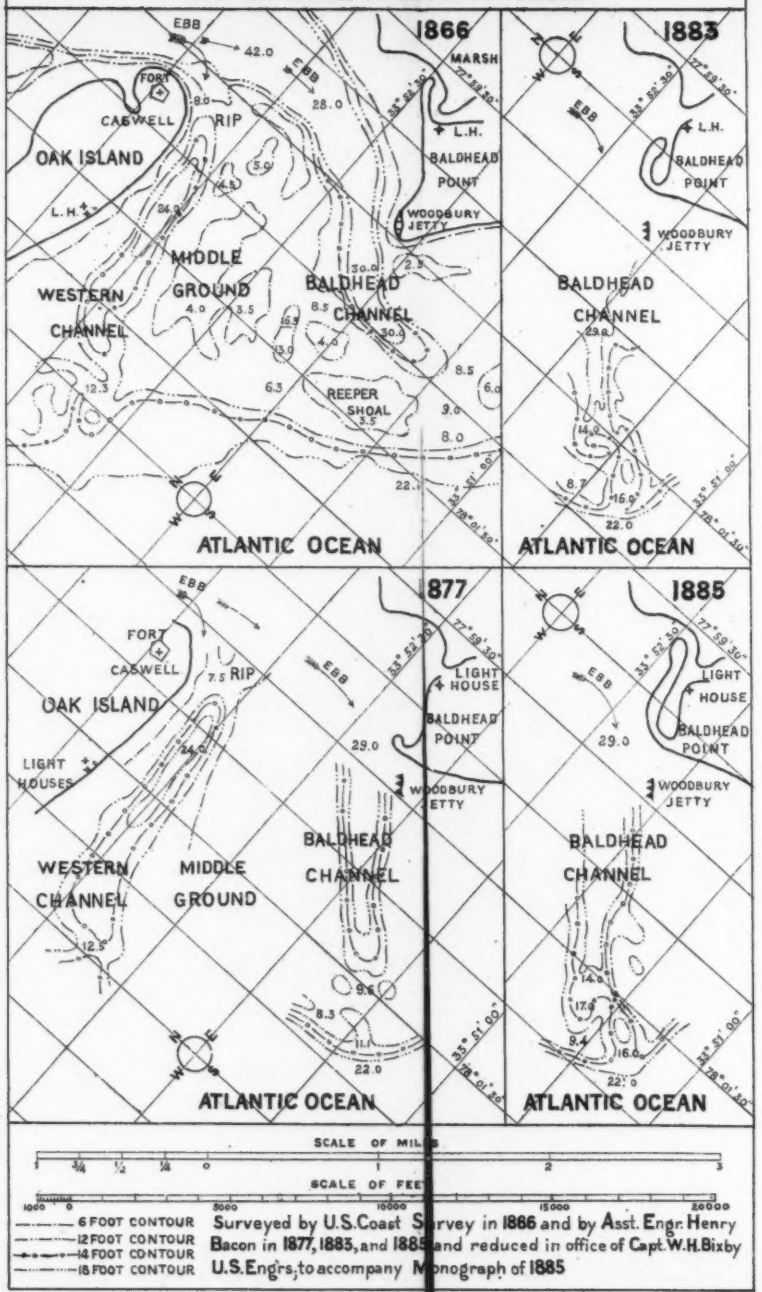

CAPE FEAR RIVER
CAPE FEAR RIVER 1852
FEDERAL POINT
NEW INLET
ZEKE'S ISLAND
HEAD OF SMITH'S ISLAND
OCEAN
SMITH'S ISLAND
BUZZARD'S BAY
CAPE FEAR 1858
NEW INLET (OPEN)
CAPE FEAR RIVER
SNOW'S MARSH
FORT CASWELL
BALDHEAD
CAPE FEAR 1877
NEW INLET PARTLY CLOSED
CAPE FEAR 1885
DAM
NEW INLET (CLOSED)
CAROLINE SHOAL
DAM UNFINISHED
Smithville
BUZZARD'S ISLAND
Swash
SCALE OF MILES
SCALE OF FEET
6 FOOT CONTOUR
12 FOOT CONTOUR
18 FOOT CONTOUR
14 FOOT CONTOUR
16 FOOT CONTOUR
Surveyed by U.S. Coast Survey in 1852, 1858, and 1866
Engr. Henry Bacon in 1877, 1885 and 1885 and reduced
Capt W.H. Bixby, U.S. Engrs, to accompany Monograph

CAPE FEAR RIVER



Surveyed by U.S.Coast Survey in 1852, 1858, and 1866 and by Asst. Engr. Henry Bacon in 1877, 1883 and 1885 and reduced in office of Capt W.H.Bixby, U.S.Engrs, to accompany Monograph of 1885.

CAPE FEAR RIVER ENTRANCE



SCALE OF MILES

SCALE OF FEET

6 FOOT CONTOUR
12 FOOT CONTOUR
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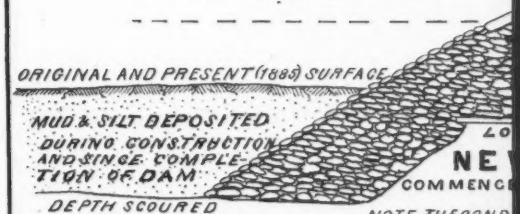
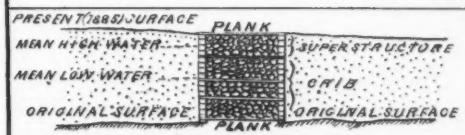
Surveyed by U.S.Coast Survey in 1866 and by Asst. Engr. Henry Bacon in 1877, 1883, and 1885 and reduced in office of Capt. W.H.Bixby U.S.Engrs, to accompany Monograph of 1885

CAPE FE
CHARACTERISTIC SECTION
NEAR THE NEW INL


OCEAN SIDE
ORIGINAL AND PRESENT (1883) SURFACE
MUD & SILT DEPOSITED DURING CONSTRUCTION AND SINCE COMPLETION OF DAM
DEPTH SCOURED

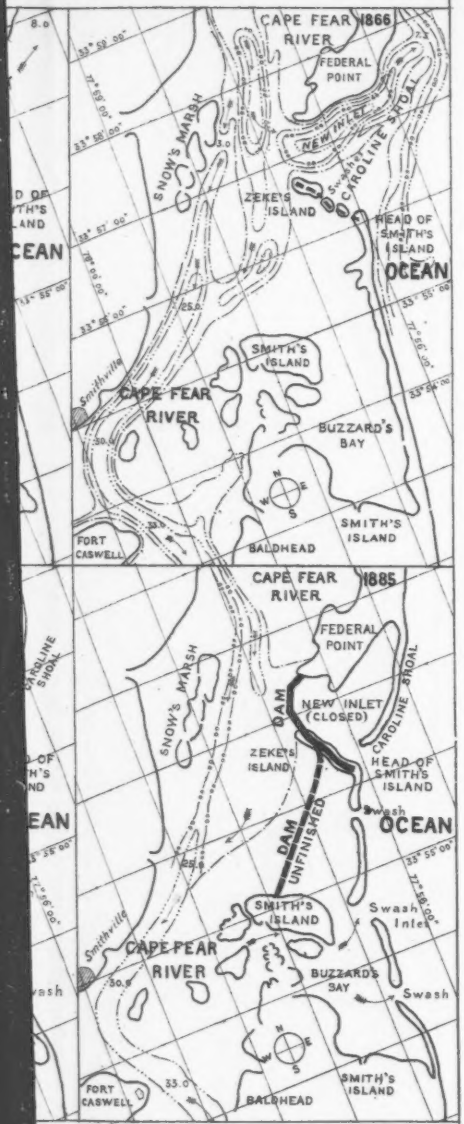
NOTE. THE COND... IS TO A GREAT EX... ARE KNOWN TO ... PLACES FROM...



OLD WORK

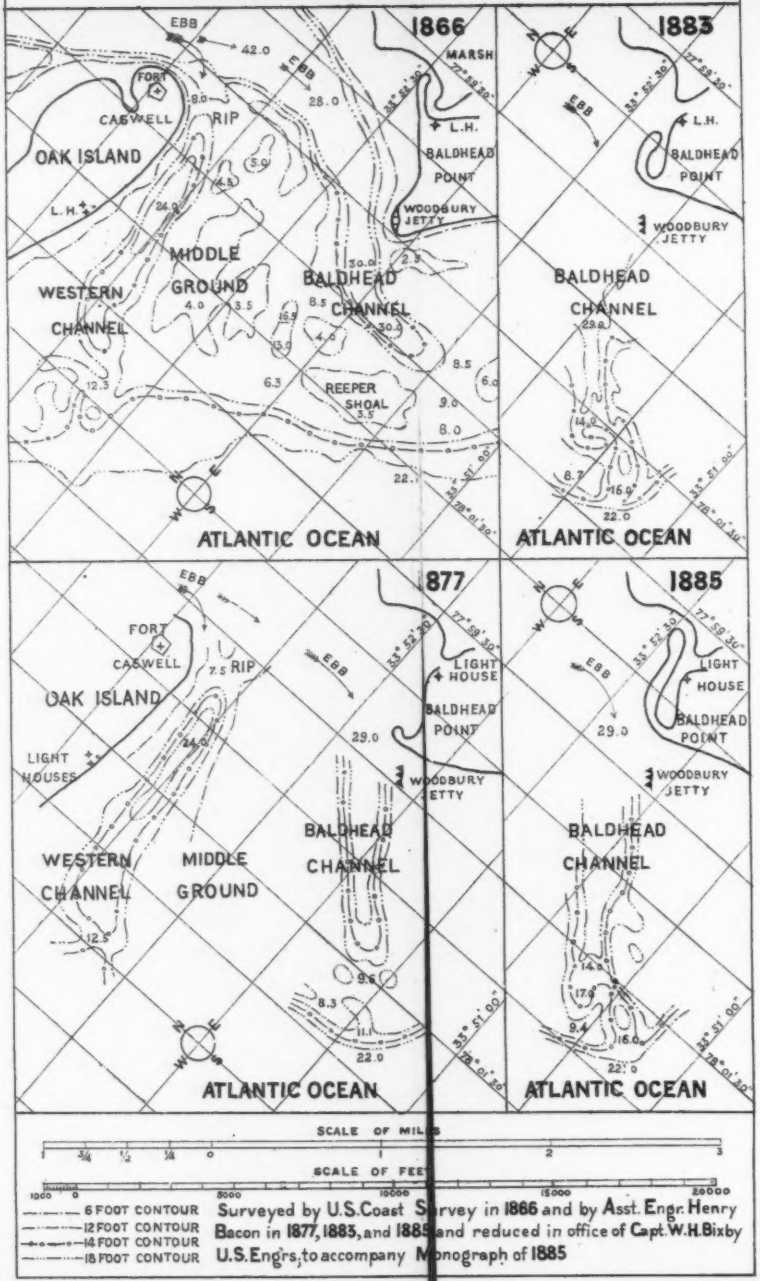
FROM HEAD OF SMITH'S ISLAND TO HEAD OF ZEKE'S ISLAND. CRIBS OF 12" x 12" TIMBER WITH OCCASIONAL CROSS TIES, SOLID SIDES AND ENDS, AND PLANK BOTTOM. SUPERSTRUCTURE, SAME, WITH OCCASIONAL CROSS TIES, SOLID SIDES AND PLANK TOP. BOTH CRIBS AND SUPERSTRUCTURE FILLED WITH STONE RIP RAP. COMMENCED IN 1870. FINISHED IN 1873

FEAR RIVER



ed by U.S.Coast Survey in 1852, 1858, and 1866 and by Asst. nry Bacon in 1877, 1883 and 1885 and reduced in office of H.Bixby, U.S.Engrs, to accompany Monograph of 1885.

CAPE FEAR RIVER ENTRANCE



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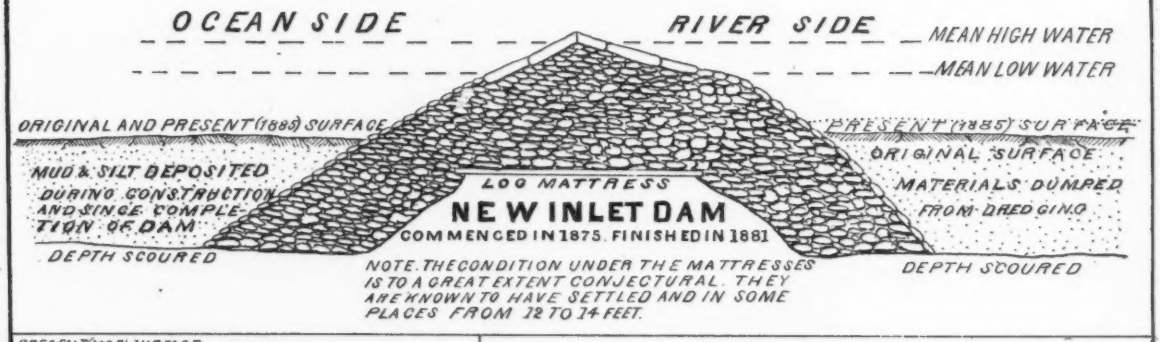
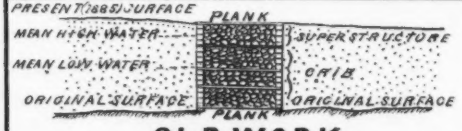
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIX Nº 399.
BIXBY ON
CAPE FEAR RIVER.

CAPE FEAR RIVER N.C.

CHARACTERISTIC SECTIONS OF THE DIFFERENT WORKS CONSTRUCTED NEAR THE NEW INLET FROM 1870 TO 1885.

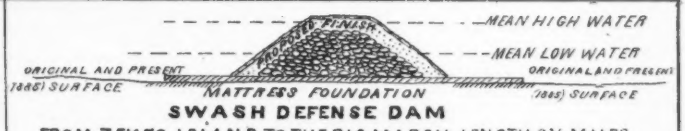


NOTE. THE CONDITION UNDER THE MATTRESSES IS TO A GREAT EXTENT CONJECTURAL. THEY ARE KNOWN TO HAVE SETTLED AND IN SOME PLACES FROM 12 TO 14 FEET.



OLD WORK

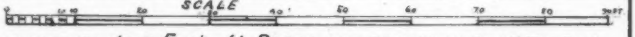
FROM HEAD OF SMITH'S ISLAND TO HEAD OF ZEKES ISLAND. CRIBS OF 12" × 12" TIMBER WITH OCCASIONAL CROSS TIES, SOLID SIDES AND ENDS, AND PLANK BOTTOM; SUPERSTRUCTURE, SAME, WITH OCCASIONAL CROSS TIES, SOLID SIDES AND PLANK TOP. BOTH CRIBS AND SUPERSTRUCTURE FILLED WITH STONE RIP RAP. COMMENCED IN 1870. FINISHED IN 1873



SWASH DEFENSE DAM

FROM ZEKES ISLAND TO THE BIG MARSH. LENGTH 3⅛ MILES

THE SKETCH SHOWS THE PRESENT CONDITION AND THE PROPOSED FINISH. COMMENCED 1883. NOT YET FINISHED.



PREPARED BY ASST. ENGR. H. BACON AND TRACED IN THE OFFICE OF CAPT. W. H. BIXBY, U.S. ENGRS TO ACCOMPANY MONOGRAPH OF 1885.

entrance in all kinds of weather at a cost of not over sixteen cents per cubic yard. This steamer was afterwards remodeled and its suction dredge apparatus much altered and improved. As altered, it worked more easily and rapidly than before, so as to dredge and pass through its bins as much as 656 cubic yards of sand in one day, at a cost of not over fifteen cents per cubic yard. The usefulness of this dredge, however, is not to be measured merely by the quantity of sand passed through its bins, inasmuch as its drags loosen and stir up from the channel bed a large quantity of material, which is carried directly into the adjacent deep water by the river and ocean currents.

During the progress of all this work, the rapidity and economy of construction were continually hampered by the lack of sufficient appropriations, which rarely, for any individual year, equalled the estimates of the engineer in charge. The lack of sufficient funds, often just at moments when those funds were most needed, has caused to the work a considerable loss of time and money.

WILLIAM R. HUTTON, M. Am. Soc. C. E.—The paper before us, avoiding much detail, is, as its author states, rather a basis for discussion by the Society of the general question presented, than of the particular works described.

It is true that the methods of river improvement are practical rather than theoretical, if by the latter we understand mere speculation. But true theory also refers to principles of general application in any art or science, and if these principles are derived from observation and experiment by others, they may be quite as valuable as anything that has taken place solely within the limited experience of any one of us. Such principles of river improvement as have been formulated are the results of such experience. Practical experience is invaluable, but it needs the aid of "theory" to yield its best results.

It was most natural that in the first attempt to improve the entrance to Baltimore, Colonel Brewerton should have adopted the shortest line, to reach deeper, unobstructed water nearer the eastern shore of Chesapeake Bay, the more so in view of the small appropriations and generally the small amount of river and harbor work at that time attempted by the general Government. The difficulty of maintaining this channel transversely to the currents of the bay was, however, recognized in Colonel Brewerton's day during our civil war.

The remedy was obvious, but it required not only the "stratum of hard common sense," (a pre-eminent quality in our author), to perceive it, but great courage to recommend at that day so radical and expensive a change. The result could not be doubtful. The currents of both ebb and flood were in the direction of the new Craighill channel; there were no ocean waves to disturb the bottom, and the freshet discharge of the Susquehanna follows apparently in great part the eastern shore of the

bay. Under these conditions a dredged channel should be easily maintained without training walls, which would here be a most inappropriate method of improvement. The sides of the cut, indeed, where of much depth act as submerged walls, and induce the greater current in the deeper water between them.

It may be doubted if the deposi of dredged material in the bay not less than a mile from the channel forces any appreciable quantity of water into the new channel or fills any other useful purpose. Its economy, however, is a justification for the practice.

JAMES RIVER.—The relative efficiency of spurs and training walls in the regulation of a water-way is well established. The former have their advantages in cheapness of first cost, facility of modification and quicker results, all powerful factors in our great country, where so much is to be done, and where results are so impatiently awaited. They are more effective and less expensive to maintain in rivers of gentle current.

The utility of the tidal reservoir between the spurs is, however, doubtful. The improvement of a tidal river is best promoted by such works as induce the tide to ascend as far as possible, by removing all obstructions to its advance through a regulated channel, narrowing gradually from its mouth, somewhat in proportion to the quantity of tidal water passing through each successive section. The spaces between spurs disturb the regular advance of the tidal wave, and prevent its ascent both by the eddies around the ends of spurs and by the quantity of water diverted from the channel to fill the "reservoirs" between them. On the Clyde large quantities of valuable land have been taken from this "reservoir," and the land reclaimed by the longitudinal dikes along the lower Seine has sold for more than the cost of the improvement.

All great improvements have been made with training walls, but they require careful location after thorough study of the stream. The Clyde, the Tees, the Seine, the Rhone, the Loire, the Maas, and the Hudson are instances.

On the James the greatest trouble seems to have been with the straight wide reaches of the river, and at points where the channel crosses from one side to the other, generally due to the changes in direction of curvature. In the former cases the difficulty has probably been excessive cost, for although a curved channel is more easily maintained than a straight one, a proper reduction of the width of the low water channel would hardly have failed of the desired effect. The latter case has been reduced to law, "la loi Fargue."

"When a river is to be treated which cannot economically be kept in proper condition by dredging, the evils may be diminished by making the curves and the width of the bed to vary gradually.

"The rules to be followed are based upon the very considerable and permanent success obtained upon the Garonne.

"Experience has shown that the curves must vary gradually, from the maximum curvature of the concave bank at the crown or summit of the curve, to nothing at the point of contrary flexure. The width also must diminish from the summit of the curve, where the bed is widest, to the point of reverse curvature, where it is much reduced." Instances are given where the width at the point of reverse curvature was with marked success reduced to 150 meters, although the width at the summit of the curve above was 200 meters and at the summit of the very sharp curve below 250 meters. "The conditions of success are also increased when the convex curves are made longer than the concave banks. We know that there is a tendency to form deposits along the convex bank. If, therefore, the banks are convex on both sides at the point where the direction changes the current, repelled from both shores, is concentrated in the middle of the stream, and the depth of the channel is increased." The rules apply also to a tidal river, on condition of a progressive increase of width, demanded by the increased discharge in the lower portions. To obtain the best results, the depth must be regulated as well as the width, but this is more necessary in non-tidal rivers with rapid currents.

The regulation of the channel by scour is not performed in very high floods or at low water. The floods of the Missouri are said to fill up at times the entire channel—to re-excavate it as the water falls, in the same or a different place, according to the conditions of the site. There is generally a stage (which has been called the regulating stage) in which the regulating works are able to control and form the bed. To this height should the work be raised. If lower, the water will escape over them and lose a part of its scouring force; if higher, the flood waters will be concentrated upon the low water bed, causing excavation in places, and dams and bars in others.

It is sometimes the case that the dredge alone can be used for forming a permanent bed, but this is possible only when the disturbing causes recur at long intervals. Most of the great works of river improvement have been the joint work of the dredge and training wall; the former has been the more largely used in Great Britain, the latter on the Continent.

The effect of a cut-off is to concentrate in a short distance the slope which before was distributed over the length of the bend. The excess of slope will in time distribute itself upon the river bed for some distance above and below the cut. The James is a tidal river with (presumably) a very slight slope at low water. It is probable therefore that important advantages could be obtained by cutting off others of the great bends in this crooked stream. Those should, however, be first made which are nearest the mouth. The disastrous floods of the River Theiss, at Szegedin, in Hungary, have been due in part to the cut-offs made only in the upper portion of the stream, which precipitated

the flood waters upon the lower valley more rapidly than they could be carried off.

The comparison of the future of Salisbury on the Wicomico with the past of Glasgow on the Clyde, recalls some facts which may be of interest here. We may, however, be permitted to doubt if any depth of water in the Wicomico will ever make of Salisbury a second Glasgow.

Glasgow existed a thousand years before America was discovered. Its *second* cathedral was commenced before A.D. 1200. Its University was founded in 1450. In 1700 it was trading largely with America. In 1770 its importations were more than half those of the United Kingdom.

In 1740 the town council appropriated $500 to deepen the channel of the Clyde. In 1755 Smeaton was consulted. In 1768 Golborne suggested spur dikes and dredging. In 1799 Rennie advised shortening some of the spurs and connecting their ends by low training walls. "This was done, and much land reclaimed." In 1755 the rise and fall of the tide in neaps (at Glasgow) was barely perceptible. In 1836 the rise of neap-tides was 4 feet, and of spring tides 7 to 8 feet. In 1878 the range was 10 feet. When the improvement was commenced the Clyde at Glasgow was but 100 feet in width. It is now over 400 feet. The work has been performed by tidal scour, largely aided by the dredge, especially in more recent years.

Although the population of Glasgow has increased ten-fold in the last hundred years, it was already a large and most important commercial centre, with a trade which demanded the improvement of its line of access to the sea.

It is to be regretted that the author was not able to give his own experience with the work on Cape Fear River. The problem was a most difficult one, involving points of very great interest. The omission has been in great part supplied by the excellent paper of Captain Bixby.

The remark is approvingly quoted that we must "aid nature." True; but nature does not always work in harmony with our desires, and it is often difficult to determine what her efforts mean. We must not rashly assume them, but after careful study of *all* the circumstances of each case we must provide the conditions under which she will do her work, whether of creation or of maintenance.

It has been said during this discussion that the best works are not those which are constructed in the most solid and permanent manner, but those which give the best and largest results for the money expended. No principle has been more fully recognized than this in the whole range of Civil Engineering in this country. It was the necessity of covering a Continent with works of art with the limited resources of private capital in a new country that has developed the peculiarities of American Engineering. It has led us to a greater originality, to look to the end and the most direct means of attaining it, without regard to methods previously employed and under different conditions in the older hemisphere.

MR. BURGWYN.—In discussing the paper before the Society, and the criticisms, or rather the enlargements, upon it, it appears as if sufficient stress had not been laid upon the essence of the paper, which is the lesson that an improvement can only be perfected after a prolonged experiment and study upon each individual subject. It is related of the late Professor Agassiz that his first lesson to his class in ichthyology consisted in giving them a fish to look at and examine for a week, and return with a written report. If the learned professor considered an entire week as necessary for the study of a single fish, it certainly ought to take many weeks, even years, for the study of so complicated a phenomenon as hydraulic action. The following table illustrates this :

DATE.	AREA IN SQUARE FEET.		FEET.	RATIO OF FEET	
	High Tide	Low Tide.	Low Tide, Width.	Low Tide, Width.	Low Tide, Max. Depth.
1874	10 244	6 008	1 200	4.97	9.2
1877	7 899	5 841	588	9.93	12.1
March, 1878	7 905	5 840	590	9.90	11.9
September, 1878	7 294	5 544	500	11.09	13.1
December, 1878	7 123	5 443	480	11.34	13.2
November, 1880	7 426	5 785	469	12.33	16.0
March, 1881	7 501	5 856	470	12.46	15.2
May, 1882	7 359	5 776	450	12.84	16.1
April, 1884	7 472	5 911	446	13.25	16.5
June, 1885	7 572	5 968	445	13.41	16.3
March, 1887	7 594	6 028	444.7	13.55	16.4
August, 1888	7 578	6 026	443.4	13.59	16.3

This table gives the cross section of the James River at the crest of Richmond Bar, and extends over an interval of fourteen years. By an examination of the third column any one would say that the area at low tide was a constant, no matter what the width of the river may be. This appears to be true, but it took fourteen years' observation and over 100 000 figures to prove it. Nor does it necessarily prove that the low tide area would be a constant at any other section; and as a matter of fact, it varies as the mouth of the river is approached—increasing, of course.

Much has been said and written on the question of experimenting upon a river. If the truth were known, it is probable that many a physician has physicked a patient first in one way, then in another. Is it not analogous for an engineer likewise to experiment?

Again, in this discussion the town of Salisbury, Md., has been instanced, comparisons having been drawn with Glasgow, Scotland. While Glasgow may always be a much greater port than Salisbury, the improvement of Salisbury harbor reacts beneficially upon the whole country. A physician tells us that if one part of the body is diseased, it necessarily affects the entire system more or less. So if Salisbury

has been improved its products will be delivered cheaper into other markets, and hence produce amelioration much further reaching than the shores of the Wicomico.

Carrying analogy further, it is seen that in algebraic solution of equations between several unknown quantities, it is necessary for solution that there should be as many equations as there are unknown quantities. So in river and harbor improvement, there must be as many physical data, and constants, as the peculiar condition demands. These can only be determined by long and careful study and experiment. The chemist has to make many a test before he can determine the element.

Mr. HUTTON.—Careful and thorough preliminary study has been already noted as necessary to successful river work. The method by experimentation, or by trial and error, has been too well illustrated by the late Captain Eads to need discussion here.*

* See Transactions Am. Soc. C. E., Vol. XV (April, 1886), pages 276, 306–328.